A

TREATISE

ON THE

SCIENCE OF SHIP-BUILDING;

WITH

OBSERVATIONS

ON

The British Navy;

THE

EXTRAORDINARY DECAY OF THE MEN OF WAR;

AND

ON THE CAUSES, EFFECTS, AND PREVENTION, OF THE DRY ROT;

ALSO, ON THE

GROWTH AND MANAGEMENT OF TIMBER TREES;

THE WHOLE, WITH A VIEW

TO IMPROVE THE CONSTRUCTION AND DURABILITY OF SHIPS.

By ISAAC BLACKBURN,
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ADDRESS TO THE READER.

IT has been long observed, and with much surprise, how greatly the ships of our enemies have excelled our own in point of sailing. A review of the wars since the French revolution of 1789, will strongly confirm this observation. Great Britain, exalted by her commerce and the prowess of her navy to the sovereignty of the seas, endures the mortifying disgrace of being behind most of the maritime powers in Europe, and that of America, in the science of ship-building, or the theory of the formation of the bodies of ships. This is, indeed, so notorious, that, in a debate on the subject in the House of Lords, on the 21st of February 1815, it was, on all hands, admitted to be the fact; and even the First Lord of the Admiralty did not scruple to declare, that the French, and even the Russian and Danish Ship-builders, were found more capable of uniting the theory of naval architecture with the practice than the English Ship-builder.

This is a disgrace, in which our Theorists and our practical Ship-builders are alike involved. One of its causes is, that the theoretical works on the subject are written in terms so abstruse, as not to be intelligible to the simple practitioner;—he cannot obtain from those works that knowledge of the laws of the resistance and restitution of water, which is indispensably necessary to

qualify him for his profession. The art labours under another disadvantage: there are no fixed principles laid down; theory, experiment, and practice, being all at variance. Mathematicians themselves maintain opposite opinions, and even experiments are found not to coincide. Practice, having thus been guided almost exclusively by experience, has made but slow advances towards improvement in the art of ship-building. There exists, moreover, in this country, a want of cordiality between the Theorist and the practical Ship-builder; the former is too little esteemed by the latter, from his having no fixed principles; and the latter is treated with indifference by the former for his ignorance in science: and both, groping in the dark, acquire no confidence in each other.

The subject is much more difficult than it is generally considered. To be thoroughly acquainted with that which is already known, it is necessary that an individual be at once a good Mathematician, a practical Ship-builder, and an experienced Seaman; and until a knowledge of these several branches be united in one person, and that he, moreover, possess great parts and sound judgment, the science will hardly emerge from its present obscurity.

What is submitted in this treatise are practical inferences drawn by the writer, from experiments made in this and other countries on floating bodies; from the opinions of different theorists; and from his own observations and experience. The writer is apprehensive, that much of what he advances may not be free from error. He considers the science to be yet extremely imperfect, and involved in much obscurity. His object is rather to render the subject familiar, by giving a more general notion of it, than to exhibit a perfect treatise. If, by his endeavours, any additional light should be thrown upon the science, and the art of ship-building receive any degree of improvement, his object would be attained. So

much does the welfare of this country depend on the efficiency of its navy, that the most humble attempt towards that object needs no other apology.

In the latter part of the work, the writer has submitted his observations on the extraordinary decay of our men of war, and on the causes, effects, and prevention of the dry-rot. The durability of our ships is an object of the greatest importance, not only with a view to economy in our finances, but it should be considered, that while the magnitude of our naval establishment has been increasing four fold, the supply of oak timber, from our native soil, has decreased in an almost equal proportion. To such a degree is our country exhausted of this valuable material, that the whole of the royal forests do not *now* furnish annually more oak timber than will build a single 74-gun ship. If the science of ship-building has improved but slowly, the art of giving durability to our ships must be allowed to have declined. The annals of the British navy furnish instances of durability in ships built formerly; which shews the art in that respect to have reached almost perfection itself, compared with its state in the present day. No other proof is necessary of this lamentable fact, than the decayed state of the navy at this moment.

This treatise being the production of one, unused, from opposite avocations, to literary pursuits, it may be proper to bespeak the indulgence of the man of letters. The writer has no pretensions to purity of style. He has expressed himself in his own homely way; and if his language should but render the subject intelligible to his readers, he trusts the importance of the matter will make up for any defects in the composition.

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CONTENTS.

BOOK I.

PART. I.

Chap.		Page
I.	*On the Resistance of Water*	1
II.	*On the Difference of the Resistance of Water at different Depths*	16
III.	*On the Velocity of Bodies moving in Water*	22
IV.	*On the Increase of the Resistance of the Water, from the Increase of the Velocity of Bodies moving therein*	26
V.	*On the Increase of the Velocity of Bodies, from the Increase of Power, to force them through Water*	30
VI.	*Difference in the Velocity of a Body of unequal Sides, when moved edgeways, and when moved flatways, through Water*	35
VII.	*Difference in the Resistance of the Water, against a Body, with Sides of unequal Dimensions; between, when it is moved edgeways, and when moved flatways, through the Water*	38
VIII.	*On the Resistance of the Water against Bow-ends of precisely the same Capacity, but of different Form*	41
IX.	*On the Increase of the Velocity of Bodies, from the Increase of Power to force them through Water, as it applies to Bodies with tapering Stern-ends*	43
X.	*On the Resistance of Water against Bodies with curved Bow-ends*	49
XI.	*On the Resistance of Water against the Bow-ends of Bodies, when not wholly immersed*	56

PART II.

I.	*On the Suction at the Stern-end of Bodies moving in Water*	58
II.	*On the Increase of the Suction of Bodies with square Stern-ends, from the Increase of their Velocity through the Water*	72
III.	*On the Impediment to the Velocity of Bodies with square Stern-ends, arising from the Suction*	75

CONTENTS.

Chap.		Page.
IV.	*On the Suction of Bodies, with tapering Stern-ends, of different Lengths of Taper*	78
V.	*On the Suction of Bodies, with tapering Stern-ends of the same Length, but of different curving*	84
VI.	*On the Suction of Stern-ends, of the same Length, and of the same Capacity, but of different Form*	90
VII.	*On Suction, as it more intimately applies to the Form of the Bodies of Ships*	92

PART III.

I.	*On the Friction of Water on Bodies, arising from their Motion in passing through it*	114
II.	*On the Increase of Friction, from the Increase of the Velocity of Bodies through Water*	122
III.	*On the comparative Proportion of the Impediments to Velocity; between that of the direct Resistance, and of the Suction, and of the Friction; as they operate on Ships*	127
IV.	*On the Difficulty of forming any regular Laws, applicable to the Resistance of Water against Bodies of similar Form to those of Ships, moving at the Velocities they usually sail at, and at the Depth in Water to which they are immersed*	132
	A useful Table of Velocity	137

BOOK II.

I.	*On the extraordinary rapid Decay of our Men of War, and the Causes pointed out*	139
II.	*On the Management of Timber Trees, and the proper Mode of bringing the Materials into Use for Ship-building, and how to procure a Supply of those of the best Quality*	153
III.	*Precautions in building the Ships submitted, and in the Care of them while in Use*	174

A TREATISE

ON

THE SCIENCE OF SHIP-BUILDING,

&c. &c. &c.

BOOK I.

PART I.

CHAPTER I.

On the Resistance of the Water.

WATER is not a simple substance, but a compound of two elements,—oxygene, or pure air; and hydrogene, or inflammable air. One hundred grains of water consists of eighty-five grains of vital or pure air, and fifteen of the base of inflammable gas or hydrogene. These are the generative principles of water; for when oxygene and hydrogene are united, they can be condensed into water. Again: water can be wholly converted into pure and inflammable air. It is also subject to expansion by heat, and obtains a repulsive power; witness its force by the steam-engine; and has also an attractive power, as is visible in drops of water, affecting to form themselves into spheres. It has, therefore, both attraction and repulsion; and where the one ceases the other operates. Heat expands and evaporates water; temperature of air preserves it in its natural state; frost expands and

congeals it. Excepting fire, water is the most penetrative of all bodies, and is even more fluid in its natural state than air, and will find its way through smaller pores. The particles are infinitely small, and not a fluid singly, but becomes so by its particles collecting together; and it is reasonable to suppose the particles must be of a spherical form, and very smooth from the extreme facility with which they are moved one against the other.

Water is considered a pure and perfect fluid, and not elastic. Some, however, suppose the particles do not touch each other, and that it is a little elastic. This, however, it is difficult to determine. It would appear that the particles are extremely near, if not quite close to each other, since water cannot be compressed into but a very little, if any smaller space than it naturally occupies; still, as steam cannot be confined, nor the expansion of water by frost be restrained, and as this power of expansion of water depends on the degree of heat or cold, it can only be in a particular state of temperature that the particles of water do touch. And since, when water is expanded in steam, and the particles do not touch each other, it cannot be confined; so also the particles of water, in their natural state, may not quite touch, and yet be incompressible. That there is a vacuity between the particles, is reasonable to suppose; and it is asserted, that a certain portion of salt, sugar, and allum, can be dissolved in water, one after the other, without at all enlarging the bulk of the water, but only adding to its weight; and that perfumes and spirits also insinuate between the particles, and occupy the place of purer essence. Admitting each particle of water to be round, there would certainly be a vacuity between them, even if they did touch each other; for two round surfaces will not join, but only touch at one place. And, therefore, if the particles do touch each other, they do so only at certain points; and where they do not touch, there will be a vacuity. And, hence, when all these vacuities are filled up, the water must lose its fluidity. And supposing, as has been asserted, that a certain portion of sugar, salt, and allum, could be dissolved, and would penetrate and fill up all the vacuities without adding to its bulk, if it be so (which some doubt), then, after as much have been dissolved in a portion of water as it will possibly take without enlarging its bulk, the difference in the weight of the water then, and in its natural state (whether the particles do or do not

touch), will be equal to the weight of so much water as would occupy a space equal to the dimensions of all the vacuities in the portion of water in its natural state. Whether, however, the particles of water do or do not touch each other, is a question by no means cleared up; in either case it is reasonable to conclude, there may be a vacuity between the particles; and hence, probably, light penetrates to, and sound is heard at, such great depths in water. And as the state of the temperature of the atmosphere affects the water, so probably the particles may be regulated in their proximity to each other.

Water is extensively susceptible of any impression or obstruction; witness the impulse of wind on its surface, or of a stone thrown into the water, how far the undulations will extend. A large stone at the bottom of a running stream will make a swell over it, the undulations of which will be perceived even at the surface, unless it lies deep; the water glides past it, and is deflected every way, over it as well as on each side of it.

By resistance is meant, that power which opposes a body in it's motion; and as it applies to the subject before us, every impediment which a body meets with in passing through the water, from any cause whatever.

Some are of opinion that the resistance and impulsion of water on similar bodies are alike; and that the force which is necessary for keeping a body immoveable in a stream of water, flowing with a certain velocity, is the same with that required for moving the body with the same velocity through stagnant water; while others are of opinion, that the pressure of the stream against a fixed body, is less than the resistance of the water against a body moving through stagnant water with the same velocity. It is difficult to conceive there can be any difference.

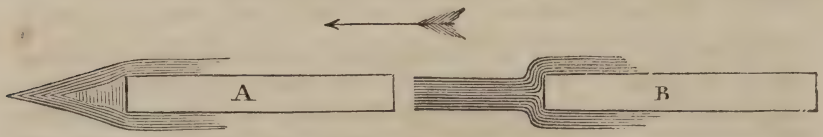
A body, moving in a stream, will go faster than the stream itself, and large bodies will move faster than smaller ones; a log of wood will outstrip a chip, and a chip move faster than saw-dust. If a body be opposed to a running stream, and a hole be made through that body, the water will pass

through the hole quicker than the stream runs—some are of opinion with near double the velocity.

Again: Water flowing through a hole in a thin plate will be increased in quantity full one-third, by adding a tube whose length is about twice the diameter of the hole.

Moreover, water running out of a hole from one side of an open vessel, will cause a recoil against the opposite side.

The velocity of a stream is very different in different parts of it—swiftest of all in the middle towards the surface, and diminishing towards the sides and bottom; hence, water in rivers runs the slowest near the banks, because the current receives a check in passing over the ground which forms its bed and banks.



Suppose a body of the above *Figure* to be impelled through the water, the first particles struck by the body will have a tendency to rebound against those immediately next to them; and some are of opinion that there would be a body of dead water forced before the body, against the water contiguous to it, similar to what is described by *Figure* A; and that the resistance of the water in such case arises from the action of the dead water against that immediately next to it; and which is partly the case when a body is moved with great velocity. Others are of opinion there is no stagnant water; but that, owing to its tenacity and friction, it has a whirling motion. Others again affirm (which is partly the case when a body is moved at slow velocities), that the water parts in the middle, and passes off each way, as described by *Figure* B; for it is known that, when water is obstructed by a flat surface, it will take a turn when it comes within a few inches of the surface, as it were by a centrifugal force, and move parallel

with the obstructing surface. And when a body is passing through the water, the water not only parts and yields side-ways, but also upward and downward—it yields in every direction with the same facility; and the water is partly divided by the body, and partly pushed forward by it, in such degree and proportion, depending on the form of the body, and also upon the velocity of the body, as will be shewn.

It may be proper to elucidate a few of the technical terms which are now about to be introduced:—by the *bow-end* of a body, is meant that end which is moved against the water; by the *stern-end*, is meant the hinder end; and the *midship-part*, that part in the midway between the ends.

It has been asserted as a physical truth, that the perpendicular resistance to the motion of a plain surface, through water, when wholly immersed, is equal to the weight of a column of water, having the surface for its base, and for its height *the* fall producing the velocity of the motion; and by the theory of the motion of bodies, it is *twice* the fall producing the velocity of the motion.

But neither of these positions coincide with experiment; it will be seen by reference to TABLE I., that the body, having one foot area of surface of resistance, immersed close below the surface of the water, and having a flat or square bow-end, requires 183 lbs. weight to obtain a velocity of 7 miles per hour, or 11,83 feet per second. This body, therefore, having one foot base, displaces 11,83 feet of water per second, and 11,83 cubic feet of water by falling $2\frac{17}{100}$ feet, obtains the velocity of 11,83 feet per second; and the weight of a column of water of one foot base and $2,\frac{17}{100}$ feet in height is only 138 lbs., whereas the actual weight of the force by experiment is 183 lbs.; and, therefore, what has been asserted as a physical truth, is 45 lbs. less than per experiment. Now the theory states it to be equal to the weight of a column of water *twice* the height of the fall producing the velocity of the body; this, therefore, would give a column of water of 1 foot base and $4\frac{34}{100}$ feet high, the weight of which, supposing a cubic foot of water to weigh 64 lbs., would be 277 lbs., and therefore the theory is 94 lbs. more than

TABLE I.

COMPARATIVE proportion of weights or powers required to force bodies through water, each of the bodies having one foot area of surface of resistance of midship-section; but in one case having sharp bow-ends, and in the other square or flat bow-ends, the bodies being impelled at different velocities through the water, in one case moved close below the surface, and in the other moved at six feet below the surface of the water:—

	When moving close below the surface of the water.				*When moving at six feet below the surface.*			
Velocity per hour.	Flat bow-ends.	Sharp bow-ends.			Flat bow-ends.	Sharp bow-ends.		
	Weight.	Weight.	Difference.	Proportion.	Weight.	Weight.	Difference.	Proportion.
Miles.	lbs.	lbs.	lbs.	Times.	lbs.	lbs.	lbs.	Times.
2	11	$4\frac{1}{2}$			21	14	7	$1\frac{1}{2}$
$2\frac{1}{2}$	19	8	11	$2\frac{3}{8}$	34	22	12	$1\frac{1}{2}$
3	27	10	17	$2\frac{7}{10}$	46	31	15	$1\frac{1}{2}$
$3\frac{1}{2}$	40	15	25	$2\frac{10}{15}$	62	41	21	$1\frac{1}{2}$
4	56	$18\frac{1}{2}$	$37\frac{1}{2}$	3	79	53	26	$1\frac{1}{2}$
$4\frac{1}{2}$	73	23	50	$3\frac{1}{6}$	103	66	37	$1\frac{1}{2}$
5	90	$30\frac{1}{2}$	$60\frac{1}{2}$	3	123	80	43	$1\frac{1}{2}$
6	144	48	96	3	180	114	66	$1\frac{1}{2}$
7	183	67	116	$2\frac{4}{6}$		153		
8		87						
9		114						
10		134						
$10\frac{1}{2}$		145						

than per experiment. And it will be seen that neither of these positions correspond with the experiments in hardly any case; but the theory is much the nearest at greater velocities, particularly to the resistance of the body when moved at six feet depth.

Some are of opinion, that every time a body of any figure moves its length in water, it divides as much water as it occupies; but it is evident this cannot be the case; for the quantum of water divided depends alone on the length of the body, and the area of the midship-section; and two bodies being alike in respect to midship-section and to length, but one having tapering bow and stern-ends, and the other square or flat ones, both will divide the same quantity of water in moving their length, but the body with the tapering bow and stern-end will occupy much less water, or have less capacity, than the other body. And here it may be observed, that the weight of any floating body, and of all it contains, is precisely equal to the weight of the water which the body occupies, or displaces when a-float.

When different formed bodies, having the same area of surface of midship-sections, are drawn through water at the *same* rate of velocity by force, power, or weights, it follows, that the force or weight required to give *each* body such velocity, must exactly counterbalance, or be equivalent, to the resistance of the water against each of them respectively. And the area of the surface of resistance of the midship-sections of such bodies being equal, and requiring different weights or powers, to obtain the same velocity through the water, it follows, that such difference in the weights or force required, must arise from the resistance of the water being either lessened or increased by the difference in the form of the bodies.

Thus the resistance, which bodies meet with in going through the water, varies materially according to the sharpness or fullness of the bow-end, as is particularized in TABLE I.

The body with a very sharp bow-end, when moved through the water close below the *surface*, obtains the same velocity, as one with a square or flat bow-end, with only about one-third of the weight or force.

The body with a sharp bow-end, moved through the water at *six feet below the surface,* obtains the same velocity as one with a flat bow-end, with about two-thirds the force. And it may be seen by the TABLE, that an equal increase of velocity may be given to a body, with a sharp bow-end, with a much less *increase* of weight than the *increase* of weight amounts to, which one with a square bow-end would require, although the area of the surface of resistance of the midship-section be alike in both bodies.

When the bow-end of a body, moving through the water, is acutely formed, or angular, the water, being in a measure divided, is inasmuch divided in the direction of the line or angle of the bow, in a similar manner as described by this *Figure;* the bow-end of which is formed like a wedge, with its edge upright.

But although such a bow-end divides the water laterally or sideways, yet it is certain, when the body is deeply immersed, that the water is also deflected upward and downward, as well as sideways; and the breadth of the water deflected is much greater than the breadth and depth of the body; and the sensible deflection begins at a considerable distance before or beyond the bow-end, and the water is in some degree forced before it: and that part of the water immediately next the body is in some measure drawn from the surrounding fluid, by its adhesion to the body, and obtains a small velocity with it, but by no means equal to the velocity of the body. The water, therefore, immediately next the body, causes a resistance from its friction against the body; and being also forced before, and drawn against the surrounding fluid, causes a resistance from its tenacity and friction against the surrounding fluid.

Some are of opinion, that this quantum of water, attracted and drawn by bodies from the surrounding fluid, remains the same, let the velocity of bodies be what it will; and that the curves, described by the surrounding fluid against the water next the body, never varies at any velocity.

And, because it has been observed, that grass, and other substances which grow to ships' bottoms, move backward and forward as if the vessels had no motion, when at the same time they have been passing through the water at the rate of four or five miles an hour; it has been thought, that the water next the vessels is stagnant, adhering to the bottoms, and accompanying them in their course—forming a kind of atmosphere;—but if this is the case, how is it that the copper on ships' bottoms wears away so soon by the friction of the water?

That the water, immediately next a body, moves with the body there is no doubt; but that it is attached to the body, and moves with the body, at the same velocity at which the body moves, certainly is not the case. It is, however, possible, that a body may never pass through the fluid immediately next to it, beyond a certain velocity, let the velocity of the body be ever so much greater.

That the water is attracted by a body in its motion—and, further, that the velocity with which it accompanies a body must be very considerable, appears beyond all doubt, by those vessels which are impelled by steam. These vessels have a wheel at each side (similar to water wheels) fixed outside of the vessels, and immersed about one-sixth of their diameter, and the wheels have sweeps or paddles round their circumference. The wheels being turned round by the power of the steam-engine, the paddles are moved against the water with a force to impel the vessel forward. In comparing the velocity of the paddle wheels, in their rotatory motion, with the velocity with which the vessel is impelled forward by them, it will be found that the velocity of some of these vessels is equal, or very nearly so, to the velocity of the paddle wheels at their circumference. The steam-vessels which go from London to Margate, have paddle wheels twenty-seven feet in circumference, and the wheels are moved round by the steam-engine thirty times in a minute The velocity of the paddles at the circumference of the wheel is, therefore, thirteen feet and a half per second, or about eight miles per hour; and it is found, that when the paddles move in the water with this velocity, those vessels move forward with the same velocity, or very nearly; namely, eight miles per hour. If, therefore, the water immediately next to the vessel (in which the paddles move) was stationary,

and the vessel only had motion, the paddles could not operate with any force against the water, the vessel moving through it with the same velocity as the paddles move against it; and the water must forsake the paddles as fast as the paddles moved to the water. It is evident, therefore, that the water immediately next to the vessel accompanies the vessel in its motion, and that with velocity enough for the paddles to act against this water with sufficient force to impel the vessel forward eight miles per hour, at the time when the paddles themselves move against the water only at the same rate.

The mutual action of bodies on each other is always exerted in a direction perpendicular to the touching surfaces, whether the surfaces are struck perpendicularly or obliquely; and thus the action of water against the bow-end of bodies operates. The more oblique or sharp the angle of the bow, the ess the direction of the action of the water operates to impede the velocity; the action of the water becomes more sideways than right against the direction of the vessel's motion. But the resistance of a fluid, when acting obliquely on a body, does not by any means decrease in the proportion to its obliquity; or, the resistance of the water against the bow of a ship, does not decrease in the proportion to the degree of its acuteness, or to the sharpness of the angle, formed by the water-lines.

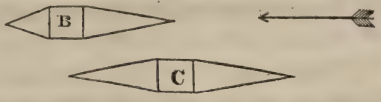
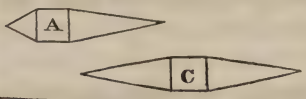
By experiments made in Sweden it appears, that bodies with sharp bow-ends obtain greater velocity through the water than bodies with full bow-ends, when by equal powers moved slowly through water; and that bodies with full bow-ends obtain greater velocity when, by equal powers, forced rapidly through water.

By experiments made in France, on the resistance of water to the bodies of ships, it appears, that the bow-end may undergo many variations without experiencing any very great difference in the resistance, provided the mid-ship bend, or section, continue the same.

Certianly, however, the resistance which a vessel meets with from the water may be considerably diminished by lengthening the taper of the bow-end, but the degree of advantage of a sharp bow in overcoming the resistance,

TABLE II.

SHEWING the difference in the weights or powers required to give the same velocity to bodies having tapering bow-ends of different lengths, each body having the same midship-part of one foot area of surface of resistance, and also the same tapering stern-end, and varying only in the length of their bow-ends; the bodies being immersed, and forced through water at six feet depth.

	Short bow-end, half the length on the angle, as the long one. 			*Short bow-end, one third the length of the long one, on the angle.* 		
Velocity miles per hour.	Weight.	Weight.	Difference.	Weight.	Weight.	Difference.
Miles.	lbs.	lbs.	more.	lbs.	lbs.	more.
$2\frac{1}{2}$	16	15	$\frac{1}{15}$	17	15	$\frac{1}{7}$
3	23	22	$\frac{1}{22}$	24	22	$\frac{1}{11}$
$3\frac{1}{2}$	32	31	$\frac{1}{31}$	34	31	$\frac{1}{10}$
4	41	41	—	45	41	$\frac{1}{10}$
$4\frac{1}{2}$	55	53	$\frac{1}{26}$	58	53	$\frac{1}{11}$
5	69	66	$\frac{1}{22}$	72	66	$\frac{1}{6}$
$5\frac{1}{2}$	86	82	$\frac{1}{20}$	90	82	$\frac{1}{10}$
6	103	99	$\frac{1}{25}$	108	99	$\frac{1}{11}$
$6\frac{1}{2}$	123	117	$\frac{1}{19}$	126	117	$\frac{1}{10}$

depends on the rate of velocity at which the vessel passes through the water.

The longest bow-end meets with the least resistance at the velocities with which ships usually sail, and the shortest bow-end meets with the most resistance at the usual velocity ; but the difference becomes less and less the faster the bodies are moved, as is seen in TABLE II.

For instance, the three bodies described in TABLE II. having each of them the same midship-part and tapering stern-ends, but different length of bow-end, one of them, C, having a bow-end three times as long on the angle as A, the shortest of them, and twice as long as B, the other one; B requires $\frac{1}{13}$ part more force or weight than C, to force it through the water at $2\frac{1}{2}$ miles per hour, and but $\frac{1}{19}$ part more weight at $6\frac{1}{2}$ miles per hour. And the shortest bow-end, A, requires $\frac{1}{7}$ part more weight than the longest one C, to go $2\frac{1}{2}$ miles per hour, and but $\frac{1}{13}$ part more weight to go $6\frac{1}{2}$ miles per hour.

Hence, it is evident how much the theory of the resistance of fluids differs with experiment in respect to bodies moving in water at these several velocities, and how difficult it is to establish any general law applicable to *different* forms of bodies, moving at *every* rate of velolicty.

The theory states, that the resistance of a fluid, when acting obliquely on a body, decreases in the proportion of the square of the angle of incidence. By experiments made in France, the difference between the resistance by the Theory and the actual resistance by Experiment, is as follows ; *viz.*

Angle of the Bow-end.	*Resistance per Experiment.*	*Resistance by the Theory.*
degrees		
180, or flat.	10,000	10,000
168	9,893	9,890
156	9,578	9,568
144	9,084	9,045
132	8,446	8,346
120	7,710	7,500
108	6,925	6,545
96	6,148	5,523
84	5,433	4,478
72	4,800	3,455
60	4,404	2,500
48	4,240	1,654
36	4,142	955
24	4,063	432
12	3,999	109

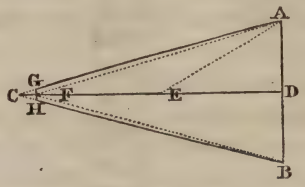
And from other experiments, made in London, it appears that the resistance, as deduced from experiment, did not follow the law of the angle of incidence, nor any regular law yet known, as will appear by the result, which is as follows; *viz.*

Angle of Incidence.			*Resistance by Experiment.*	*Resistance by Theory.*
°	′	″	lbs.	lbs.
9	44	10	30·67	24·71
14	28	10	35·34	37·06
19	25	15	41·71	49·42
30	0	0	51·44	74·13

Therefore the theory leads to conclusions exceedingly erroneous, as respects the rate of velocities tried by experiments, and the error increases in proportion as the angle of incidence becomes more acute, and the velocities

of the bodies thus far accelerated. Certainly the theory cannot be relied upon, as it respects the subject under consideration.

Doubts (as to those velocities) may be reasonably entertained of the truth of the following position of Sir Isaac Newton, relating to the resistance of the frustrum of a cone; *viz.*



Of all conical bodies, having the circle whose diameter is A B for its base, and F D for its height; the one which sustains the smallest impulse, or meets with the smallest resistance, is the frustrum A G H B of a cone, A C B so constructed that E F, being taken equal to E D, E A is equal to E C. This frustrum, A G H B, though more capacious than the cone A F B of the same height, will be less resisted.

It is a question, if the *difference*, which the resistance of the two angles A F B and A C B meet with from the water, is not less than the resistance of the plane surface, G H, moved against the water, at least at the velocities in question.

As the water is in some measure driven before, and also accompanies a body in its motion in a partial degree of the velocity of a body, the bow-end sustains an intimate resistance of the water, in the proportion in which it actually passes through the water immediately next to it; and the water immediate next the body sustains a resistance (from its tenacity and friction) in moving against the surrounding fluid, according to the velocity with which it accompanies the body. The body sustains the direct resistance in these two ways.

It is reasonable to suppose, that the water immediately next to, and struck

by the bow-end, will be in a measure forced before it, against that contiguous to it; for the contiguous water would yield to the water struck by the bow-end (fluid against fluid), as readily as the water immediately next the bow would yield to the bow. And, however acute the angle of the bow-end, the water would still be forced before it in a degree, and more and more so as the velocity of the body increased, till at a certain velocity the water would be forced forward nearly in as great a degree as if the bow was obtuse. An obtuse bow drives the water before it more than the acute bow in slow motions, but in more rapid motions they force the water before them more alike. This accounts for bodies with full bow-ends obtaining *great* velocities with the same powers as those with sharp bow-ends, the water being forced forward nearly as much by one bow as by another at great velocities. And hence, it also happens, that the comparative difference in the velocities of bodies, with different formed bow-ends, is found by experiment to vary, when tried at different rates of velocity, as has been shewn.

An acute bow passes only through the water immediately next to it faster than an obtuse bow; neither of them divide and pass through the water with the whole velocity at which they move forward. Bodies with different formed bow-ends, therefore, only divide and pass through the water immediately next to them differently; the resistance, both in respect to the sharp and full bow-end, being in part the action of the water immediately next the body against the surrounding fluid: and this part of the resistance is always the same at the same impulse, let the form of the bow-end be what it may.

The resistance of water to the motion of bodies, moving at the velocity ships sail at, being thus of a compound nature, it cannot be surprising that experiment does not accord with theory, in respect to its resistance against bodies with bow-ends of different degrees of acuteness. The acute bow-end can only obtain the advantage of the obtuse bow, from that part of the velocity with which it actually passes through the water immediately next the body, and not in the proportion to the whole velocity with which the body moves forward. This accounts for the resistance of water (as per experiment) when acting obliquely on a body not following the law of the sine of the angle of incidence; the resistance, as it relates to the angle of the bow-end, operating only partially.

CHAPTER II.

On the Difference of the Resistance of Water at different Depths.

IT has been a received opinion, that the resistance of water is greater at greater depths; and the effect of deep immersion is still much contested. Various are the opinions that have been formed.

According to some, the difference in the resistance of water, at different depths, is as the square root of the depth at which the moving body is immersed; that is, that the resistance is double at four times the depth, triple at nine times the depth, &c. in a similar proportion to the velocity with which water issues out of a container, through different holes of the same size, at different depths—which is, as the square root of their depth below the surface of the water; in which case it requires *four* times the pressure or depth to make *double* the quantity of water run out,—*nine* times the pressure to discharge *triple* the quantity of water, &c.

According to others, the resistance of water, at different depths, increases in the proportion to the increase of the pressure or weight of the water at different depths. The weight of a column of water ten feet high, is ten times as great as one of one foot high; and, therefore, the pressure of water from its weight is ten times greater at ten feet depth than it is at one foot depth: and consequently the resistance of the water, according to such opinion, is ten times greater at ten feet depth than at one foot depth.

Others again affirm, that a body, deeply immersed in water, is less resisted

than when moving with the same velocity near the surface : so contradictory and various have been the opinions on this point.

When it is considered how much the pressure of water, arising from its weight, increases in proportion to its depth, it is easy to imagine, that the resistance from water may also be greater below the surface, and that it increases with increase of depth. But the resistance which a body meets with in moving through water at any depth below the surface, is not increased so much as the weight or pressure of water against the body increases at such depth ; for although the pressure from the weight of the water against a ship's bottom, at six feet depth, may be six times greater than it is at one foot below the surface, yet the resistance is not increased in any such proportion. Indeed, the pressure of water cannot increase its resistance so much as the pressure increases at different depths ; the particles yielding to each other, and being also continually supported by each other while yielding to the moving body. It is very different from the effect of the pressure of water forcing or running out of the bottom of a container ; for, in that case, the stream, running in the air, loses its support : and in consequence becomes subject to the pressure of the whole weight of the water above the aperture.

When a ship is at anchor in a tide's-way with a rapid current against her, if the water moves in a body, and not quicker at one depth than at another, the particles would strike against the bow-end of the vessel with the same force only at every depth, notwithstanding the pressure is different at different depths : and it is more similar to this when a ship is moving through the water.

Water is subject to the same laws as other fluids, as air, wind, &c. ; the weight of the particles of water are the same at different depths ; and although the compression of the water, on the bodies and air-bladders of fish, prevent them from going to great depths, yet fish swim at all the different depths usually occupied by them with nearly the same ease, notwithstanding the difference in the pressure of the water.

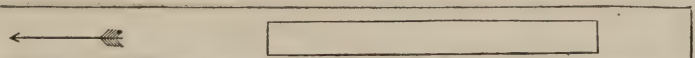
It has, however, been proved from experiments, that the resistance of water below the surface is, at the velocities tried, greater than nearer to it. By referring to TABLE III. the difference will be seen; the body (a parallelopiped), with a flat or square entrance (or bow-end), requires ($\frac{7}{9}$ more) near double the weight or power to force it through the water at a depth of six feet, than at close below the surface, when impelled at the rate of two miles an hour; and when moved at the rate of 6 miles an hour, it requires ($\frac{3}{9}$ more) one-third more power to force it through the water at six feet depth, than at close below the surface. But, then, the difference of the resistance of water at the surface, and at six feet depth, lessens considerably as the velocity of the body increases; for at a velocity of $2\frac{1}{4}$ miles per hour, the difference in the weight is nearly double; and at a velocity of 6 miles an hour, it is only one-third, as will appear by reference to TABLE III. And, therefore, the difference of the resistance of water at different depths, depends on the rate of the velocity of the bodies moving therein, which will be more fully shewn hereafter.

At most of the different velocities, *under seven miles* per hour, bodies, with sharp bow-ends, require more than double the weight or force to draw them through the water at six feet depth, than they do to draw them through the water close below the surface. The difference of the resistance of water against bodies with *sharp bow-ends*, between when they are moving close below the surface, and when moving at six feet under water, *lessens* however with *increased* rate of velocity.

By taking a comparative view of TABLES III. and IV. it will be seen, that it requires 15 lbs. additional weight to give the body, having a *flat bow-end*, the same velocity at six feet under water as at close below the surface, when moving at the rate of $2\frac{1}{2}$ miles per hour; and that it requires 14 lbs. additional weight to give a body, with a *sharp bow-end*, the same velocity at six feet depth as at the surface, when moving at $2\frac{1}{2}$ miles per hour. And, further, that it requires 45 lbs. additional weight to give a body, with a *flat bow-end*, the same velocity at six feet under water as at close below the surface, when moving at the rate of 6 miles per hour; and

TABLE III.

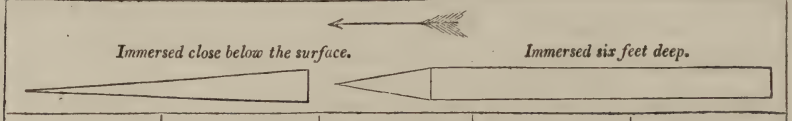
SHEWING the difference in the weight or power required to force a body through water, between, when it is moved *close below* the surface, and when it is moved at *six feet below the surface*, brought into a comparative view. The body (a parallelopiped one foot square), has one foot area of surface of resistance opposed flat against the water, and moved at different velocities.



Velocity through the water.	Weight required to overcome the resistance close below the surface.	Weight required to overcome the resistance at six feet below the surface.	Difference additional weight.	Proportional difference.
Miles per hour.	lbs.	lbs.	lbs.	more.
2	11	21	10	$1\frac{10}{11}$
$2\frac{1}{2}$	19	34	15	$1\frac{7}{9}$
3	27	46	19	$1\frac{4}{6}$
$3\frac{1}{2}$	40	62	22	$1\frac{1}{2}$
4	56	79	23	$1\frac{3}{5}$
$4\frac{1}{2}$	73	103	30	$1\frac{3}{7}$
5	90	123	33	$1\frac{1}{3}$
6	145	180	45	$1\frac{3}{9}$
7	183			

TABLE IV.

SHEWING the difference in the power or weight required to force a body through water, between, when it is moved close below the surface, and when it is moved at 6 feet depth in the water; placed in a comparative view at different velocities. The bodies have each one foot area of surface of resistance, and moved with the sharp-end forwards.



Velocity through the water.	Weights required close below the surface.	Weights required six feet below the surface.	Difference additional weight.	Proportion.
Miles per hour.	lbs.	lbs.	lbs.	more.
2	—	14	—	—
$2\frac{1}{2}$	8	22	14	$2\frac{3}{4}$
3	10	31	21	3 times
$3\frac{1}{2}$	15	41	26	$2\frac{11}{15}$
4	$18\frac{1}{2}$	53	$34\frac{1}{2}$	3
$4\frac{1}{2}$	23	66	43	$2\frac{10}{14}$
5	$30\frac{1}{2}$	80	$49\frac{1}{2}$	$2\frac{3}{5}$
$5\frac{1}{2}$	—	96	—	—
6	48	114	66	$2\frac{9}{24}$
7	67	153	86	$2\frac{1}{3}$
8	87			
9	114			
10	134			
$10\frac{1}{2}$	145			

that it requires 66 lbs. additional weight to give a body, with a *sharp bow-end,* the same velocity at six feet depth as at the surface, when moving at the rate of 6 miles per hour.—And, therefore, the difference in the resistance of the water near the surface, and at six feet depth, depends on the form of the bow-end, as well as on the rate of the velocity of the body.

The *flat bow-end* requires more *additional* weight than the *sharp bow-end,* when moving at $2\frac{1}{2}$ miles per hour; and the *sharp bow-end* requires more *additional* weight than the *flat bow-end,* when moving at 6 miles per hour, in order to obtain the same velocity at six feet depth, as at close below the surface of the water. But it must be observed, that an equal *increase* of velocity, of from $2\frac{1}{2}$ to 6 miles per hour, is given to the body having a *sharp* bow-end, with but 40 lbs *additional* weight, when the one with a *flat* bow-end requires 126 lbs. *additional* weight: both bodies being moved close below the surface of the water. And when moving at six feet depth in water, the *sharp* bow-end requires but 92 lbs. *additional* weight, and the *flat* bow-end 146 lbs. *additional* weight, to obtain the said increase of velocity of from $2\frac{1}{2}$ to 6 miles per hour. And the *flat* bow-end requires 86 lbs. additional weight more than the *sharp* bow-end to obtain this increase of velocity, when moved close below the surface, and only 54 lbs. additional weight more than the sharp bow-end to obtain this increase of velocity, when moved at six feet below the surface of the water.

Thus, therefore, the difference of the resistance of water at different depths, depends upon the velocity of the bodies, and also upon the form of the bow-end of such bodies.

CHAPTER III.

On the Velocity of Bodies moving in Water.

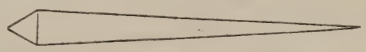
WHEN bodies of *equal area* of surface of resistance, or of midship section, are forced through water; and they obtain *different* velocities with the *same* power or weight; it follows, that such difference in the velocities can only arise from the difference in the *form* of such bodies.

Bodies having either sharp, or flat bow-ends, obtain with the same weight or force, a greater velocity when moving close below the surface of the water, than when moving at six feet depth; at every rate of velocity under ten miles an hour.

Bodies with *sharp* bow-ends, obtain greater velocity with the same weights or powers, than those do having *flat* bow-ends, when moving through the water at any depth, and at every rate of velocity at which ships usually sail.

Two bodies forced through the water close below the surface, both having the same breadth and depth, and figure, only one having a flat bow-end,

and the other having an equilateral triangle added to the bow-end, and



both acted upon by the same weight or power; the one with a triangular bow-end, will obtain a velocity of 5,17 feet in the space of time, while the one with a flat bow-end, goes but 3,61 feet; and 8,32 feet, while the flat bow-end goes but 6,54 feet. The body with a sharp bow-end

obtains $\frac{5}{12}$ more velocity, than the one with a flat bow-end, at the slowest rate of motion before-mentioned; and but $\frac{3}{12}$ more velocity only, at the greatest rate of motion.

It is evident, therefore, that the *difference* in the velocity of the two bodies when acted upon by the same weight, become less and less, the faster the bodies are moved.

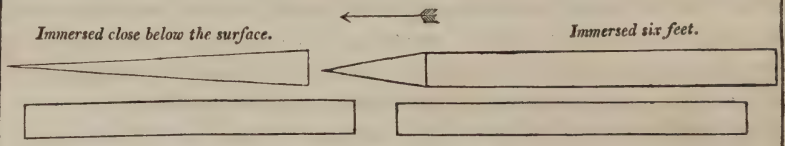
TABLE V. exemplifies further particulars: two bodies forced through the water *close below the surface*, having the same length, breadth, depth, and area of surface of resistance; but one having a square or flat bow-end, and the other an acute angle terminating at its bow-end; and each acted upon by the same weights or powers; the one with a sharp bow-end will, with $11\frac{1}{2}$ lbs. weight, obtain a velocity of 5,59 feet in the space of time, while the other with a flat bow-end goes but 3,51 feet; and, with 145 lbs. weight, the sharp bow-end goes 17,77 feet, while the flat bow-end goes 10,18 feet.

And, further, it appears, that the two bodies forced through the water at 6 *feet depth*, the one with a sharp bow-end will, with $11\frac{1}{2}$ lbs. weight, obtain a velocity of 3,00 feet in the space of time, while the one with a flat bow-end goes but 2,49 feet; and with 145 lbs. weight, the one with a sharp bow-end will go 11,68 feet, while the other with a flat bow-end goes 9,19 feet.

Therefore, with the *additional* weight ($133\frac{1}{2}$ lbs.), the flat bow-end obtains an *increase* of velocity when moving close below the *surface* of the water of 6,67 feet, and 6,70 feet when moving at 6 *feet* below the surface: whereas the sharp bow-end obtains an *increase* of velocity when moving close below the *surface* of the water of 12,20 feet, and only 8,68 feet when moving at 6 *feet* depth. So that from the same *increase* of weight ($133\frac{1}{2}$ lbs.), the body with a *flat* bow-end obtains a *greater increase* of velocity when moving through water at six feet depth, than it does when moving close below the surface; and in this instance the body with a *sharp* bow-end obtains *less increase* of velocity when moving through water at six feet depth, than it does when moving close below the surface.

TABLE V.

EXHIBITING a comparative view of the difference in the velocities, given to bodies with sharp and flat bow-ends, when acted upon or forced through the water by equal weights or powers, and when moving close below the surface of the water and at six feet depth: the several bodies having precisely the same area of surface of resistance; *viz.* one superficial foot.



Different Weights to give Velocities.	Moving at the Surface of the Water.		Moving at Six Feet below the Surface.	
	Sharp Bow-end.	Flat Bow-end.	Sharp Bow-end.	Flat Bow-end.
lbs. weight.	Velocities. Feet per sec. dec. parts.	Velocities. Feet per sec. dec. parts.	Velocities. Feet per sec. dec. parts.	Velocities. Feet per sec. dec. parts.
6	——	——	2,14	1,77
11½	5,59	3,51	3,00	2,49
15	6,00	3,89	3,43	2,80
23	7,63	4,64	4,35	3,56
30	8,80	5,37	4,99	4,06
46	9,98	6,18	6,44	5,07
60	11,15	6,96	7,25	5,83
64	11,52	7,17	7,49	6,02
69¼	12,05	7,42	7,80	6,27
90	13,86	8,45	8,97	7,17
93	14,12	8,54	9,13	7,30
116	15,45	9,31	10,27	8,18
120	15,70	9,47	10,46	8,33
139	17,31	9,99	11,32	8,99
145	17,77	10,18	11,68	9,19
150		10,43	11,17	9,30
180		11,68		10,14
183		11,83		

The *flat* bow-end with $11\frac{1}{2}$ lbs. weight, obtains $\frac{4}{10}$ more velocity when moving close below the surface than when moving at six feet depth in water; but, with 145 lbs. weight, it obtains only $\frac{1}{10}$ more velocity close below the surface, than at six feet depth. The *sharp* bow-end, with $11\frac{1}{2}$ lbs. weight, obtains $\frac{8}{10}$ more velocity at the surface of the water, than what it has when moving at a depth of six feet; but, with 145 lbs. weight, it obtains only $\frac{5}{10}$ more velocity when moving at the surface of the water, than it has when moving at six feet depth.

Therefore, as the power or weight by which the bodies are acted upon is increased, or the greater the rate of the velocity becomes at which they are impelled, the less the difference of the resistance of the water becomes at different depths.

CHAPTER IV.

On the Increase of the Resistance of the Water, from the Increase of the Velocity of Bodies moving therein.

THE resistance of water against bodies, when moved through it at different velocities, increases very powerfully with the increase of velocity. If a ship moves through the water at the rate of four miles an hour by a certain force from her sails, it would require much more than double that force in order to double her velocity, or to go eight miles an hour.

According to the theory, the resistance which bodies meet with in passing through fluids, increases with the velocity or space run through: and therefore the resistance is as the velocity itself. And, moreover, the resistance increases also, in proportion to the force with which the body strikes against every particle of the fluid; and, consequently, if the velocity be triple from a triple number of particles to be removed, it is also triple from a strake three times stronger against every particle. Therefore the whole resistance in this case becomes ninefold, or as the square of the velocity; that is, if the velocity was increased double, then would the resistance be four times as great,—the square of two being four; if the velocity was increased fourfold, then would the resistance be sixteen times as great,—sixteen being the square of four (four times four).

And it is a general received opinion in hydraulics, that it requires a fourfold pressure to produce double velocity, a nine-fold pressure to produce triple velocity, and a sixteen-fold pressure to produce four times increase of velocity, &c. &c.

This theory of the general laws of fluids does not, however, exactly correspond with experiment; in respect to the motion of bodies in water, at the velocities tried, it will be found to vary as they move at different depths in water, and also to vary according to the form of the bow-end, and also (more particularly) according to the form and length of the taper of the stern-end of bodies, as will be shewn hereafter; and it will be found also to vary in a small degree, according as the bodies are moving at the quicker or slower velocities through the water.

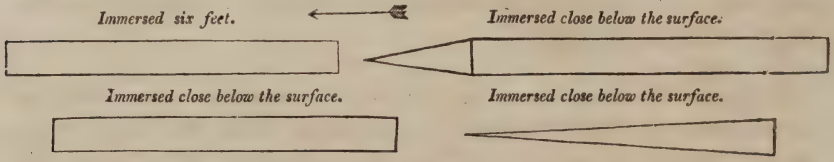
In TABLE VI. the particulars are shewn: the body with a sharp bow-end requires rather less than four times the weight to double the velocity when moving through the water at *six feet below the surface;* but when moving *close below* the surface, it requires above four times the weight to double the velocity. And, further, the sharp bow-end requires about eight times the weight to triple the velocity, when moving through the water at *six feet* below the surface; but when moving *close below* the surface, the sharp bow-end requires ten times the weight to triple the velocity. Furthermore, the sharp bow-end requires fourteen times the weight to obtain four times the velocity, when moving at *six feet depth* in the water; but when moving *close below* the surface, it requires seventeen times the weight to obtain four times increase of velocity.

And in like manner (as will be seen by the TABLE), the body with a flat bow-end requires a greater proportional increase of weight, in order to obtain double, triple, or four times increase of velocity, when moving at the surface, than it does when moving at six feet depth in the water. Therefore, bodies require a greater proportional increase of power or weight to obtain increased *rate* of velocity, when moving close below the surface, than they do when moving at six feet below the surface of the water.

It will be seen also in TABLE VI. that the body with a flat bow-end requires rather a greater proportional increase of weight to obtain double, triple, or four times the velocity, than the body with a sharp bow-end, both when moving close below the surface, and at six feet depth below the surface. And, consequently, it would appear in this case, that the fuller

TABLE VI.

SPECIFYING the proportional rate of the increase of weight or power, as required to be increased, in order to give double, triple, and quadruple velocities to bodies impelled through water, both when moving close below the surface, and also when moving six feet below the surface of water: the bodies having sharp and also flat bow-ends, each of them one foot area of surface of resistance.



Increased rate of velocity.	Velocity.	Flat Bow-ends.		Sharp Bow-ends.	
		Moving at the surface.	At six feet below.	At the surface.	At six feet below.
	Miles per hour.	Weight. lbs. Difference.	Weight. lbs. Difference.	Weight. lbs. Difference.	Weight. lbs. Difference.
Double	1½	.....	11½		
	3		46 } four times.		
	2	11 } five times	21 } near	4½ } above	14 } not
	4	56 } more.	79 } four times.	18 } four times.	53 } four times.
	2½	19 } near	34 } near	.....	22 } near
	5	90 } five times.	123 } four times.		80 } four times.
	3	27 } above	46 } near	10 } near	31 } near
	6	144 } five times.	180 } four times.	48 } five times.	114 } four times.
	3½	40 } near	.....	15 } above	41 } near
	7	183 } five times.		47 } four times.	152 } four times.
	4	.....	.....	18½ } above	
	8			87 } four times.	
	5	.....	.....	30 } above	
	10			134 } four times.	
Triple	1½	.....	12 } near		
	4½		103 } nine times.		
	2	11 } thirteen	21 } near	.....	14 } eight times.
	6	144 } times.	180 } nine times.		114 }
	2½	15 } twelve.	.....	.....	20 } near
	7	183 } times.			153 } eight times.
	3	.....	.....	10 } above ele-	
	9			114 } ven times.	
	3½	....	.....	15 } near	
	10½			145 } ten times.	
Four times	1½	.....	12 } fifteen		
	6		180 } times.		
	1½	8 } twenty-three	.....	.....	11 } fourteen
	7	183 } times.			153 } times.
	2½	.....	.....	8½ } seventeen	
	10½			145 } times.	

the bow-end of the body is, the greater the *proportional* increase of the weight or power becomes which is required to obtain any *increased rate* of velocity, whether the body is moved close below the surface of the water; or at six feet depth below the surface of the water; in other instances, however, this differs.

It must, moreover, be observed, that double or triple increase of velocity is given to the body with a sharp bow-end, with a much less additional weight than the one with a flat head-end requires. For a body with a sharp bow-end requires less power or weight to force it through water at any rate of velocity ships sail at, and at any depth they occupy, than a body with a flat bow-end. And although when the respective powers or weights to each are doubled, they both acquire nearly the same proportional increase of velocity, yet the *additional* weight to the body with a sharp bow-end will be much less than to the one with a flat bow-end. For instance, the body with a sharp bow-end, moving at six feet depth in water, requires only 100lbs. additional weight; and the body with a flat bow-end requires 159lbs. addititional weight in order to obtain triple velocity from two to six miles per hour. And the body with a sharp bow-end, moving close below the surface of the water, requires only 43 lbs. additional weight; and the body with a flat bow-end requires 133lbs. additional weight to triple the velocity from two to six miles per hour.

CHAPTER V.

On the Increase of the Velocity of Bodies from the Increase of Power to force them through the Water.

BODIES of every figure, and when moving through water at any depth, obtain an increase of velocity from an increase of weight or power, or of the impelling force.

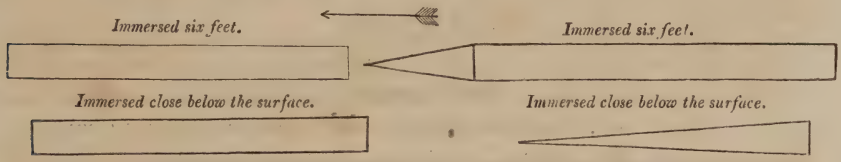
By increasing the weight or power to double, triple, or four times as much, the *velocity* of bodies is not, however, increased near so much in the same proportion. For, as will appear by the particulars in TABLE VII., bodies moving in water do not obtain much more than one-third additional velocity from double the increase of weight or power, and not much more than two-thirds additional velocity from triple the increase of weight, and not much more than double the velocity from four times the increase of weight or power.

The increased *rate* of velocity, from double, triple, or four times increase of weight, varies by experiment at different depths in water in which the bodies may be moved, and varies also from the difference in the form of bodies, and in some instances (owing to the latter circumstance) from the degree of rapidity at which the bodies are moved.

By experiment, bodies with flat or square bow-ends, and those also with sharp bow-ends, obtain a greater increased *rate* of velocity, from double, triple, or quadruple increase of weight, when they are moved at *six feet* below the surface of the water, than they do when moved *close below* the surface, at the velocities, and as is specified in TABLE VII.

TABLE VII.

SHEWING the proportional increase of the velocity of bodies through water, when acted upon by double, triple, and quadruple increase of weight or power: the bodies having sharp and also flat bow-ends, and have each one foot area of surface of resistance, and moved through the water close below the surface, and also at six feet below the surface.



Increased rate of Weights.	Weight. lbs.	With flat Bow-ends. Moving at the surface. Velocities. Ft. per Sec.	Diff.	With flat Bow-ends. At six feet below. Velocities. Ft. per Sec.	Diff.	Sharp Bow-ends. Moving at the surface. Velocities. Ft. per Sec.	Diff.	Sharp Bow-ends. At six feet below. Velocities. Ft. per Sec.	Diff.
Double	11½	3,51	5/17 Increased	2,49	5/12 Increased	5,59	3/8 Increased	3,00	4/9 Increased
	23	4,64	more.	3,56	more.	7,63	more.	4,30	more.
	15	3,89	7/19	2,80	5/11	6,00	7/13	3,42	4/9
	30	5,37		4,06		8,80		4,99	
	23	4,64	1/3	3,56	3/7	7,63	3/16	4,30	5/11
	46	6,21		5,07		9,98		6,29	
	30	5,37	2/7	4,06	3/7	8,80	2/7	4,99	5/11
	60	6,96		5,83		11,15		7,25	
	46	6,18	4/11	5,07	3/7	9,98	4/9	6,29	5/11
	93	8,54		7,30		14,12		9,13	
	60	6,96	4/11	5,83	5/12	11,15	2/5	7,25	5/12
	120	9,47		8,33		15,70		10,16	
	69½	7,42	4/11	6,27	5/14	12,05	4/9	7,80	5/11
	139	9,99		8,99		17,31		11,32	
	90	8,45	4/16	7,17	5/12				
	180	11,68		10,14					
Triple	15	3,89	4/7	2,80	9/11	6,00	2/3	3,42	9/11
	46	6,21		5,07		9,98		6,29	
	30	5,37	6/11	4,06	7/9	8,80	7/12	4,99	9/11
	90	8,45		7,17		13,86		8,97	
	46	6,18	3/5	5,07	7/9	9,98	3/4	6,29	8/16
	139	9,99		8,99		17,31		11,32	
	60	6,96	7/16	5,83	3/4				
	180	11,68		10,14					
Four times	11½	3,51	3/4	2,49	1 1/24	5,59	7/9	3,00	1 1/11
	46	6,18		5,07		9,98		6,29	
	15	3,89	7/9	2,80	1 1/12	6,00	6/7	3,42	1 1/9
	60	6,96		5,83		11,15		7,25	
	23	4,64	9/11	3,56	1 1/21	7,63	5/6	4,30	1 1/8
	93	8,54		7,30		14,12		9,13	
	30	5,37	9/12	4,06	1 1/20	8,80	7/9	4,99	1 1/10
	120	9,47		8,33		15,70		10,46	
	46	6,21	7/8	5,07	1 double				
	180	11,68		10,14					

The body with a *sharp* bow-end obtains rather a greater increased *rate* of velocity, from double, triple, or quadruple increase of weight, than the body with a *flat* bow-end, both when moved close below the surface of the water, and also at six feet depth in water. This circumstance, however, does not correspond in respect to bow-ends of a different degree of fulness, as will be shewn hereafter.

The body with a *sharp* bow-end, when moved through the water *close below the surface* with $11\frac{1}{2}$lbs. weight, obtains a velocity of 5,59 feet in a second of time; and, when moved with twelve times that weight (139 lbs.), obtains 17,31 feet in a second, which is $3\frac{1}{10}$ times the velocity.

The body with a *flat* bow-end, when moved *close below* the surface of the water with $11\frac{1}{2}$lbs. weight, obtains a velocity of 3,51 feet in a second; and when moved with twelve times that weight (139lbs.), obtains a velocity of 9,99 feet, which is $2\frac{8}{10}$ times the velocity.

And, further, the body with a *sharp* bow-end, when moved through the water at *six feet depth* with $11\frac{1}{2}$lbs. weight, obtains a velocity of 3,00 feet in a second; and when moved with twelve times the weight (139 lbs.), obtains a velocity of 11,32 feet, which is $3\frac{7}{10}$ times the velocity.

The body with a *flat* bow-end, when moved at *six feet depth* in water with $11\frac{1}{2}$lbs. weight, obtains a velocity of 2,49 feet in a second; and when moved with twelve times that weight (139 lbs.), it obtains 8,99 feet, or $3\frac{6}{10}$ times the velocity.

But although the body with a *sharp* bow-end obtains a greater increased rate of velocity from twelve time the weight, when moved through the water at six feet depth, than it does when moved close below the surface; yet the sharp bow-end, when moving close *below the surface*, has the most *additional* velocity, obtaining an *addition* of velocity of 11,72 feet in a second; when the sharp bow-end, when moved at *six feet below* the surface of the water, has an addition only of 8,32 feet, from the same additional weight of 127 lbs. But the body with a *flat* bow-end not only obtains a

greater increased *rate* of velocity, but actually a greater *additional* velocity, when moving through the water at six feet depth, than when moving close below the surface of the water; obtaining at six feet depth an additional velocity of 6,50 feet in a second, and only 6,48 feet when moving close below the surface of the water—being acted upon in each case with the same additional weight of 127 lbs. Hence, it is evident that the difference of the resistance against the body with a *flat* bow-end, moving through the water close below the surface, and moving at six feet depth, *lessens* with the increase or rapidity of the velocity. Further,

With 46 lbs. weight, the body with a *flat* bow-end, when moved through the water *close below the surface*, obtains a velocity of 6,18 feet in a second of time; with twelve times that weight (552 lbs.); therefore, as before observed, it will obtain $2\frac{8}{10}$ times more velocity; *viz.* 17,55 feet in a second, or near $10\frac{1}{2}$ miles per hour. And, with 46 lbs. weight, the body with a *flat* bow-end, when moving at *six feet depth* in water, obtains a velocity of 5,07 feet in a second; with twelve times that weight (552 lbs.), therefore, as before observed, it will obtain $3\frac{6}{10}$ times more velocity, which is 18,30 feet in a second, or near eleven miles per hour. And consequently the body with a *flat* bow-end would obtain *greater* velocity with the *same* weight, when moving at *six feet depth*, than when moving close below the surface of the water, if impelled at a velocity of ten or eleven miles an hour.

The *difference* to the resistance of the body with a *sharp* bow-end, moving close below the surface of the water, and moving at six feet below the surface, *lessens* with the increase or rapidity of velocity; but then, *in this case*, so very gradually, that even at a velocity of more than fifty miles per hour, the resistance of water against the body with a *sharp* bow-end is still less when moving at the surface, than when moving at six feet depth below it. But it must be observed, that if these bodies had tapering stern-ends, they would obtain the same velocity with the same weight at six feet depth as at the surface of the water, when moving at the rate of $13\frac{1}{4}$ miles per hour; as will be shewn hereafter.

And, further, with 23 lbs. weight, the body with a *sharp* bow-end, when

moved through the water *close below* the surface, obtains a velocity of 7,65 feet in a second of time; with twelve times that weight (276lbs.) it will obtain, therefore, as has been shewn, $3\frac{1}{10}$ times the velocity; *viz.* 23,57 feet in a second, or about fourteen miles per hour. And, with 23lbs. weight, the body with a *sharp* bow-end, when moved through the water at the depth of *six feet below* the surface, obtains a velocity of 4,30 feet in a second; with twelve times that weight (276lbs.), therefore, it will obtain, as before observed, $3\frac{7}{10}$ times more velocity; *viz.* 15,91 feet in a second, or about $9\frac{1}{2}$ miles per hour.

The body with a *sharp* bow-end, not only obtains a *greater* increased *rate* of velocity, from double, triple, or quadruple weights, more than the body with a *flat* bow-end, but also a greater *additional* velocity, from the same increase rate of weight, in almost all cases when moving through the water, either close below the surface, or at six feet below the surface.—A sharp bow-end to a body is therefore by far the most preferable for velocity, when moved through the water at any depth occupied by ships, and when impelled at any rate of velocity ships usually sail at.

CHAPTER VI.

Difference in the Velocity of a Body of unequal Sides, when moved edgeways through Water, and when moved flatways.

TABLE VIII. describes two bodies, of the same length, breadth, depth, and figure, each being three times wider one way than the other; one floating flatways on the water and the other edgeways, with their upper surfaces even with the surface of the water, and are moved flatways and edgeways through the water at different velocities.

It will be seen in TABLE VIII., that the body, when moved flatways through the water, obtains, with the same weight or power, a greater velocity than when moved edgeways, at every different rate of velocity *therein specified;* but the body obtains a greater *increased rate* of velocity from double, triple, or four times increase of weight, when moved *edgeways*, than when moved flatways.

The body, when moved flatways with 67lbs. weight, obtains a velocity of 3,892 feet in a second of time; with (804lbs.) twelve times that weight it obtains 11,687 feet, which is three times the velocity. The body, when moved edgeways with 67lbs. weight, obtains a velocity of 3,331 feet in a second; with (804lbs.) twelve times that weight, it obtains 11,080 feet, which is $3\frac{3}{10}$ times the velocity. Therefore the body obtains a greater increased *rate* of velocity from twelve times the weight also, when moved edgeways through the water (*viz.* $3\frac{3}{10}$ times), than it does when moved flatways (*viz.* three times only).

The body, when moved *flatways* with 268lbs. weight, obtains a velocity of 6,960 feet in a second of time; with twelve times that weight (3216lbs.)

TABLE VIII.

SPECIFYING the difference in the velocity of two bodies of the same bulk and figure, when moved edgeways, and when moved flatways, through the water, by equal weights or powers; the bodies being wider one way than the other; shewing also the difference in the increased rate of the velocities of the bodies in each position, when acted upon by double, triple, or four times increase of weight.

Bodies, a Parallelopipedon		Ft.
	Length	42,19
	Breadth	3,66
	Depth	1,21
	Area of end	4,471

Moved with the upper surface even with the water's edge.

Increased rate of weight.	Weight to give velocity. lbs.	Moving flatways. Velocity. Ft. per sec. dec. pts.	Increased rate of velocity.	Moving edgeways. Velocity. Ft. per sec. dec. pts.	Increased rate of velocity.
	67	3,892	full $\frac{1}{3}$ more	3,331	$\frac{3}{7}$ more
	134	5,371		4,766	
	134	5,371	full $\frac{1}{4}$ more	4,766	$\frac{3}{8}$ more
Double	268	6,960		6,530	
	268	6,960	full $\frac{1}{3}$ more	6,530	$\frac{3}{8}$ more
	536	9,470		9,166	
	402	8,450	full $\frac{1}{3}$ more	8,021	$\frac{3}{8}$ more
	804	11,687		11,080	
	134	5,371	$\frac{7}{13}$ more	4,766	$\frac{16}{23}$ more
Triple	402	8,450		8,021	
	268	6,960	$\frac{15}{23}$ more	6,530	$\frac{2}{3}$ more
	804	11,687		11,080	
	67	3,892	$\frac{15}{19}$ more	3,331	$\frac{10}{11}$ more
Four times	268	6,960		6,530	
	134	5,371	$\frac{13}{17}$ more	4,766	nearly double.
	530	9,470		9,166	

it will obtain therefore 3 times the velocity; *viz.* 20,880 feet in a second, or about $12\frac{1}{4}$ miles an hour. And the body when moved through the water *edgeways* with 268lbs. weight, obtains a velocity of 6,530 feet in a second, with twelve times that weightt, (3216lbs.) it will obtain therefore $3\frac{3}{10}$ times the velocity, 21,718 feet in a second; or $12\frac{3}{4}$ miles per hour.

Therefore the body, if impelled at this rapid rate, would obtain a greater velocity from the same weight when moving *edgeways*, than when moving *flatways* through the water. And also a greater *additional* velocity with equal increase of weight: for with the increase of weight, (*viz.* 2948lbs.) the body moving *edgeways*, would obtain an *additional* velocity of 15,18 feet in a second; and the body moving *flatways*, an additional velocity of only 13,92 feet in a second. Thus by accelerating the velocity of the body, the body when moving *edgeways* through the water, is not only impelled at a greater increased *rate* of velocity, but also obtains *greater velocity*, and more *additional* velocity from the same increase of weight, than when moving *flatways*. From which it appears, that in the quicker motions, this body obtains with equal weight or powers, more velocity when moving edgeways, than when moving flatways through the water; and that in slower motions, it obtains the most velocity flatways.

CHAPTER VII.

Difference in the Resistance of the Water against a Body with Sides of unequal Dimensions, between when it is moved Edgeways, and when moved Flatways in the Water.

TABLE IX. specifies the proportional increase of weight or power required to force those bodies through the water, at double and triple rates of velocity, when moved edgeways, and when moved flatways. The figures of the bodies, and their dimensions, are described in TABLE VIII.

The body when moved flatways through the water, obtains double and triple rate of velocity, with less *additional* weight, than when moved edgeways, at the different velocities therein specified. But the body moving flatways in the water, requires a greater increased *proportion* of weight to obtain double and triple velocity, than when moving edgeways: for instance.

The body when moved *flatways* at the rate of $2\frac{1}{4}$ miles per hour, requires 67lbs. weight; and when moved at double that velocity, ($4\frac{1}{2}$ miles,) it requires 329lbs., which is near five times the weight. The body when moved *edgeways* at the rate of $2\frac{1}{4}$ miles per hour, requires 90lbs. weight; and when impelled at double that velocity, ($4\frac{1}{2}$ miles,) it requires 365lbs., which is only four times the weight.

Again, the body when moved *flatways* through the water at the rate of $2\frac{1}{4}$ miles per hour, requires 67lbs. weight; and when impelled at triple that velo-

TABLE IX.

SHEWING the difference in the weights or power required to give a body, of unequal diameter of side, the same velocities through the water, when placed edgeways as when placed flatways, and also the proportional increase of weight required to double and triple the velocities of the body in each position.

The Figures of the Bodies are described in TABLE VIII., *and are moved with their upper Surface even with the Surface of the Water.*

Velocity.		When placed flatways.		When placed edgways.	
Increased rate of Velocity.	Miles per hour.	Weights. lbs.	Difference.	Weights. lbs.	Difference.
Double	$2\frac{1}{4}$	67	near five times	90	four times
	$4\frac{1}{2}$	329		365	
Double	3	121	full five times	157	full four times
	6	624		684	
Double	$3\frac{1}{2}$	179	full four and a half times	222	full four times
	7	826		944	
Triple	$2\frac{1}{4}$	67	eleven times and a half	90	nine times and a half.
	$6\frac{3}{4}$	774		865	

city, ($6\frac{3}{4}$ miles,) it requires 774lbs. weight, which is $11\frac{5}{10}$ times more weight; and further, the body when moved *edgeways* at $2\frac{1}{2}$ miles per hour, requires 90lbs. weight; and when impelled at triple that rate, ($6\frac{3}{4}$ miles,) it requires 865lbs., which is nearly $9\frac{6}{10}$ times more weight.

The body when moved through the water *flatways* at a velocity of $4\frac{1}{2}$ miles per hour, requires 329lbs. weight. To force it through the water at triple rate of velocity, ($13\frac{1}{2}$ miles,) it will require, as before shewn, $11\frac{5}{10}$ times more weight, which is 3799lbs. The body when moved through the water *edgeways*, at a velocity of $4\frac{1}{2}$ miles per hour requires 365lbs. weight. To force it through the water at triple rate of velocity, ($13\frac{1}{2}$ miles,) it will require $9\frac{6}{10}$ more weight as before shewn, which is 3507lbs. Therefore, the body requires less weight when moving *edgeways* through the water, than it does when moving *flatways*, in order to obtain a velocity of $13\frac{1}{2}$ miles per hour.

Moreover, the body when impelled through the water *flatways*, requires 3407lbs. additional weight, in order to obtain the increase of velocity from $4\frac{1}{2}$ to 13 miles an hour; but the body when moving *edgeways*, requires only 3142lbs. *additional* weight. Wherefore, the body when moving *edgeways*, not only requires less weight to obtain the velocity of $13\frac{1}{2}$ miles per hour, but also requires less *additional* weight to obtain the increase of velocity from $4\frac{1}{2}$ to $13\frac{1}{2}$ miles per hour, than when moving *flatways*.

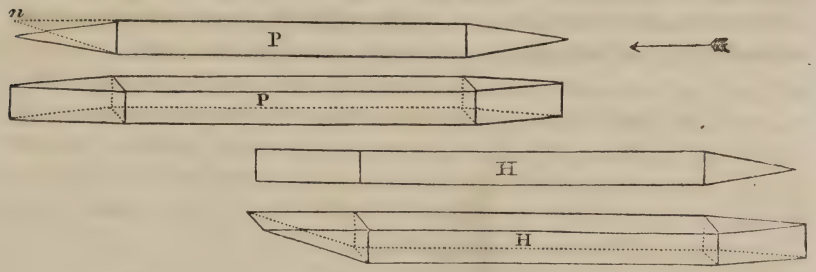
The bodies however under consideration, are of very different proportional dimensions to those of ships, and the form of the bow and stern ends very different: that the results of the foregoing are not very applicable to the consideration of bodies of the form of ships; but only serves to shew, that the difference in the resistance of water, at different depths, depends on the rate of the velocity of the bodies.

CHAPTER VIII.

On the Resistance of the Water against Bow-ends of the same Capacity, but different Form.

THERE is a difference in the resistance of the water against bow-ends of precisely the same bulk or capacity, owing to the difference in their form, arising from the difference in the direction in which the water is struck and divided by them.

The bodies moved at six feet depth.



The above sections of two *Figures*, P and H, describe bodies with bow-ends precisely of the same bulk or capacity, but of different form; the one, P, strikes and divides the water on each side of the bow, in a perpendicular direction; and the other, H, in an horizontal direction, on one part only, whereby the angle becomes more obtuse; for the bow strikes the water at the under part only of H. The bodies have one foot area of midship-section, and the midship-parts and stern-end of both bodies are the same.

P obtains, with the same weight or power, more velocity than H, at every rate of velocity from $1\frac{1}{4}$ to 7 miles per hour; *viz.* as 12,36 feet is to 11,88

feet in a second.—P also obtains more additional velocity than H, from the same increase of weight; *viz.* as 10,10 feet is to 9,68.—P also obtains a greater increased *rate* of velocity, from twelve times increase of weight, than H; *viz.* as $3\frac{7}{100}$ times is to $3\frac{73}{100}$ times.

Therefore, it is evident—it is more important to velocity in this case, to form the bow-end like P; because, the angle meeting in the middle, becomes more acute; and the water is divided on two sides; and easier divided, than by the bow-end H; which, forming a direction across the body, the water is divided on one part only; and which, becoming more obtuse in consequence, is more unfavourable for dividing the water.

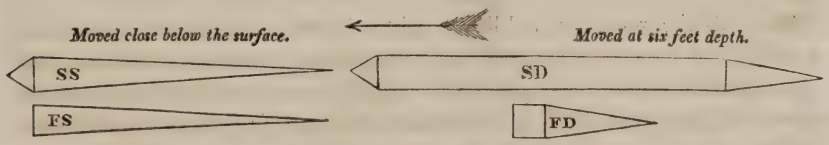
It makes no difference, whether the water is divided in an horizonal or perpendicular direction, since water offers precisely the same resistances either way; for the very same difference would arise, if the bow-end P was formed according to the dotted line angle *n*; and the water, in one case, divided by it perpendicularly in that direction, on one side only, and in the other case, perpendicularly on both sides, by the angle meeting in the middle.

CHAPTER IX.

On the Increase of the Velocity of Bodies from the Increase of the Power to force them through Water, as it applies to Bodies with tapering Stern-ends.

REFERRING to what has been said in Chap. V. of the figures described in TABLE VII. it will occur, that as those figures have not tapering stern-ends, the result of the observations (although pretty near) cannot correctly apply to the form of ships, which have tapering stern-ends, and not square stern-ends, as there described; for the form of the stern-end causes a difference in the velocity of bodies, and of course in the total resistance, as will be particularly exemplified hereafter.

The following *Figures* describe bodies with sharp bow-ends, and also with flat or square bow-ends, and each with *tapering* stern-ends:—SS, the sharp bow-end, moving through the water close below the surface; FS, the *flat* bow-end, moving close below the surface; SD, the sharp bow-end, moving through the water at six feet depth; and FD, the flat bow-end, moving at six feet depth: each body having one foot area of surface of resistance.



SS, with the power of 11½ lbs. weight, obtains a velocity of 5,17 feet in a second of time; with four times that weight or power (46 lbs.), it obtains $1\frac{6}{10}$ increased *rate* of velocity; *viz.* 832 feet; and with the increase of weight (34½ lbs.), the additional velocity is 3,15 feet in a second.—FS, with the power of 11½ lbs. weight, obtains a velocity of 3,61 feet in a

second of time; with four times that weight or power (46 lbs.), it obtains $1\frac{8}{10}$ increased *rate* of velocity; *viz.* 6,54 feet; and with the increase of weight ($34\frac{1}{2}$ lbs.), the additional velocity is 2,91 feet in a second.—SD, with the power of 12 lbs. weight, obtains a velocity of 3,17 feet in a second of time; with four times that weight (48 lbs.), it obtains $2\frac{1}{10}$ increased *rate* of velocity; *viz.* 6,65 feet in a second; and with the *increase* of weight (36 lbs), the *additional* velocity is 3,47 feet in a second.—FD, with the power of 12 lbs. weight, obtains a velocity of 2,94 feet in a second; with four times that weight (48 lbs), it obtains $1\frac{9}{10}$ increased *rate* of velocity; *viz.* 568 feet in a second; with the *increase* of weight (36 lbs.), the *additional* velocity is 2,74 feet in a second of time.

From which it appears, that bodies, both with square and sharp bow-ends, obtain a greater increased *rate* of velocity from quadruple increase of power or weight, when they are moved at *six feet depth*, than when moved close below the surface of the water.

And, further, the body with a flat or *square* bow-end, obtains rather a greater increased *rate* of velocity from quadruple increase of weight, than the body with a *sharp* bow-end, when moved through the water close below the *surface*.—And, the body with a *sharp* bow-end obtains a greater increased *rate* of velocity from quadruple increase of weight, than the body with a *flat* bow-end, when moved through the water at *six feet* depth.

SS, with the power of $11\frac{1}{2}$ lbs. weight, obtains a velocity of 5,17 feet in a second of time; with twelve times that weight (139 lbs.), it obtains $2\frac{7}{10}$ times increased *rate* of velocity; *viz.* 13,95 feet in a second; and with the *increase* of weight ($127\frac{1}{2}$ lbs), the *additional* velocity is 8,79 feet in a second. —SD, with the power of 12 lbs. weight, obtains a velocity of 3,17 feet in a second of time; with twelve times that weight (144 lbs.), it obtains $3\frac{4}{10}$ time increased *rate* of velocity; *viz.* 11,95 feet in a second; and with the *increase* of weight (136 lbs), the *additional* velocity is 8,78 feet in a second. —FS, with the power or force of $11\frac{1}{2}$ lbs. weight, obtains a velocity of 3,61 feet in a second of time; with twelve times that weight (139 lbs.), it obtains

$2\frac{9}{10}$ times increased *rate* of velocity; *viz.* 10,70 feet in a second; and with the *increase* of weight ($127\frac{1}{2}$ lbs.), the *additional* velocity is 7,09 feet in a second. —FD, with the power of $11\frac{1}{4}$ lbs. weight, obtains a velocity of 2,88 feet in a second of time; with twelve times that weight (139 lbs.), it obtoins $3\frac{7}{10}$ times increased *rate* of velocity; *viz.* 9,41 feet in a second; and with the *increase* of weight ($127\frac{1}{2}$ lbs.), the *additional* velocity is 6,53 feet in a second.

And, further, SS, with the power of 46 lbs. weight, obtains a velocity of 8,32 feet in a second of time; with (552 lbs.) twelve times the weight, it will obtain, as has been before observed, $2\frac{7}{10}$ times increased *rate* of velocity; *viz.* 22,46 feet in a second, which is about $13\frac{1}{4}$ miles per hour; and with the *increase* of weights (506 lbs.), the *additional* velocity is 14,14 feet in a second. SD, with the power of 48 lbs. weight, obtains a velocity of 6,65 feet in a second of time; with (576 lbs.), twelve times the weight, it will obtain, as has been before observed, $3\frac{4}{10}$ times increased *rate* of velocity; *viz.* 22,61 feet in a second, which is about $13\frac{1}{4}$ miles per hour; and with the *increase* of weight (528 lbs.), the *additional* velocity is 15,96 feet in a second.

Hence it is evident, that the *difference* of the actual resistance of the water, against the body with a *sharp* bow-end, between, when moving at *six feet depth*, and when moving close below the *surface* of the water, *lessens* by increasing the rapidity of the velocity; for the body with a *sharp* bow-end obtains *equal* velocity with *equal* weights or powers, when moving at *six feet depth*, as when moving close below the *surface*, at the velocity of $13\frac{1}{4}$ miles per hour. Moreover, the body with a *sharp* bow-end obtains, in most instances, *more additional* velocity from the same increase of weight, when moving at *six feet depth* in water, than when moving close below the *surface*, at every rate of velocity under $13\frac{1}{4}$ miles per hour.

FS, with the power of $69\frac{1}{2}$ lbs. weight, obtains a velocity of 7,70 feet in a second of time; with (834 lbs.) twelve times the weight it will obtain, as has been before observed, $2\frac{9}{10}$ times increased rate of velocity; *viz.* 22,99

feet in a second, which is about 13½ miles per hour; and with the *increase* of weight (764 lbs.), the *additional* velocity is 15,22 feet in a second. And, further, FD, with the power of 69½ lbs. weight, obtains a velocity of 6,83 feet in a second of time; with (834 lbs.) twelve times that weight it will obtain, as has been before observed, 3 2/10 times increased *rate* of velocity; *viz.* 22,33 feet in a second, which is about 13½ miles per hour; and with the *increase* of weight (764½ lbs.) the additional velocity is 15,50 feet in a second.

Hence it is evident, that the *difference* of the actual resistance of the water against the body with a square or flat bow-end, between, when moving at *six feet depth*, and when moving close below the *surface* of the water, *lessens*, by increasing the rapidity of the velocity. For the body with a *flat* bow-end obtains *equal* velocity with *equal* weights or powers, when moving at *six feet depth*, as it does when moving close below the *surface* of the water, at a velocity of 13½ miles per hour.

The body with a *flat* bow-end, moved *at this rapidity*, obtains more *additional* velocity from the same increase of weight, when moving at *six feet depth* in water, than when close below the *surface:* but at the lower rate of velocities it is different; at eleven miles an hour and under, it obtains *less additional* velocity from the same increase of weight, when moving at *six feet depth* in water, than when moving close below the *surface*.

The body with a *sharp* bow-end obtains greater velocity than the body with a square or *flat* bow-end, when forced through the water by equal weights or power, at any rate of velocity which ships sail at, and at the depth in water before-mentioned. Moreover, the body with a sharp bow-end obtains a greater *additional* velocity than the body with a flat bow-end, when moving through the water at the different depths, and at those rates of velocity by equal increase of weight.

The sharp bow-end is, therefore, to be preferred for velocity in a very essential degree; for it will be seen, that the flat bow-end requires 834lbs. weight to obtain a velocity of 13½ miles per hour, and the sharp bow-

end but 576lbs. weight when moving through the water, either close below the surface, or at six feet depth.

It has been observed, that the difference of the resistance of water at different depths, depends on the rate of the velocity of the body through the water; and that the body must be impelled at the rate of 13 miles per hour, before it can obtain with the same power or weight, the same velocity at six feet depth in the water, as at the surface. It would appear, therefore, that the same body must be impelled at a much greater rate, to obtain the same velocity, with the same weight, at twelve feet depth, as at the surface; and it would appear, judging from the velocity required to equalize the resistance at 6 feet depth, and at the surface, that it would require a velocity of 26 miles per hour at 12 feet depth, and 39 miles an hour at eighteen feet depth, in order to obtain the same velocity with equal weight at those depths, as at the surface.

And as ships frequently swim eighteen feet deep in the water, some more, and others less than that, and seldom obtain greater velocity than 14 miles an hour; it follows, that the resistance of the water is always greater on that part of the area of the surface of resistance, which is at the lower parts of the bottom of ships, than on those parts nearer the surface of the water. Therefore, because that water in the case before us is more easily divided and displaced near the surface than below it, it becomes very important, with a view to accelerate the velocity of ships, that the midship-section (or midship-bend) of ships should be so formed, as to have the principal capacity or bulk near the surface of the water, or within *six feet* of it, (as at *that* depth the resistance is the same as at the surface, when ships sail at their greatest rate of velocity). And by diminishing the bulk of the midship-section (or body) below, as much as it is increased nearer the surface, the ship will have precisely the same buoyancy and capacity; and her resistance from the water be thereby lessened.

In chapter the 1st., it was observed, that the water next to a body was attracted by it, and accompanied it in its motion; but then with less velocity than the body moved forward. That part of the attracted water immediately

next to the body moves with it the fastest; that further off slower; and so on, till at a certain distance from each side of the body the water becomes stationary. How much the quantum or extent of this water may be contracted by the pressure of the surrounding fluid, when a body in motion is more deeply immersed; and in what proportion it may be contracted at different depths by the collapsing weight of the fluid; and also in what degree the velocity of the attracted water may be altered thereby; and how much the velocity of the body itself may be affected by these circumstances; are considerations which invite attention, with a view to the accounting for the difference in the velocities of a body when moving with the same powers at different depths in water. Perhaps at a certain depth, the pressure of the water against a body becomes too powerful for the attraction of a body to carry any with it in this manner in its motion; in which case the resistance of the water would be purely against the body itself; its velocities then become more regular; and, probably, at such depths experiment would accord better with theory, than it is found to do, at and near the surface of the water. Again, as the resistance of water, per experiment, increases with increase of velocity, more in proportion from such increase of velocity, nearer the surface than at greater depths; it is very possible, if a body could be impelled with such extraordinary swiftness through the water, as that of sixty or eighty miles an hour, that the resistance would be found less below the surface (to a certain depth) than nearer to it; and further, that there may probably be an equal resistance at every depth at some prodigious rates of velocity; and those resistances more conformable to the theory, than the resistances, per experiment, is found to be at the velocities under consideration.

CHAPTER X.

On the Resistance of Water against Bodies with curved Bow-ends.

THE figures in TABLE X. describe three bodies, having the same midship-part and stern-end, and the same *length* of bow-end; but one having a bow-end with a straight (water) line, another with a small curve, and the other with a very round or full curved line, to divide the fluid. These three bodies are moved through the water at six feet depth. The figure, whose bow-end is formed with a small curve obtains the most velocity, and the one with a full curve the least velocity, when forced through the water with equal power or weights, at every rate of velocity under $6\frac{1}{2}$ miles per hour; and also (as will be shewn) at greater velocities.

When these three bodies are forced through the water with *double* the weights or power, they all obtain precisely the same proportional increased rate of velocity; *viz.* $1\frac{37}{100}$ times more; but the straight line obtains the *most additional* velocity; and the full curve the *least additional* velocity from *equal increase* of weight or power. When they are forced through the water with *triple* the weight or power, the straight line, and the full curve, obtain a greater proportional increased *rate* of velocity (*viz.* $1\frac{65}{100}$), than the small curve (*viz.* $1\frac{64}{100}$); but the small curve obtains the *most additional* velocity, and the full curve the *least additional* velocity, from *equal increase* of weight or power. When they are forced through the water with *quadruple* the weights or power, the straight line and the full curve obtain a greater proportional increased *rate* of velocity (*viz.* $1\frac{88}{100}$), than the small curve does (*viz.* $1\frac{87}{100}$;) but the small curve obtains the *most additional* velocity, and the full curve the *least additional* velocity, from *equal increase* of weight or power.

With 12lbs. weight, the body with a bow-end formed with a small curve, obtains a velocity of 3,93 feet in a second of time; with ten times that weight (120lbs.) it obtains a velocity of 11,17 feet in a second, which is $2\frac{84}{100}$ times more velocity. With 12lbs. weight, that with a straight line obtains a velocity 3,88 feet in a second; with ten times that weight (120lbs.) it obtains a velocity of 11,12 feet in a second, which is $2\frac{86}{100}$ times more velocity With 12lbs. weight, the one with a full curve obtains a velocity of 3,85 feet in a second; with ten times that weight (120lbs.) it obtains a velocity of 11,05 feet in a second, which $2\frac{87}{100}$ times more velocity.

Moreover, with 72lbs. weight, the small curve obtains a velocity of 8,86 feet in a second of time, or $5\frac{1}{4}$ miles per hour; with ten times increase of weight (720lbs.,) it will obtain (as has been shewn) $2\frac{84}{100}$ times more velocity, which is 25,18 feet in a second, or about 15 miles an hour. With 72lbs. weight, the straight line obtains a velocity of 8,80 feet in a second; with ten times increase of weight (720lbs.,) it will obtain (as has been shewn) $2\frac{86}{100}$ times more velocity, which is 25,19 feet in a second, or about 15 miles per hour. With 72lbs. weight, the full curve obtains a velocity of 8,74 feet in a second; with ten times that weight (720lbs.,) it will obtain (as has been before shewn) $2\frac{87}{100}$ times more velocity, which is 25,10 feet in a second, or about 15 miles per hour. Therefore, the *three* bodies would obtain a velocity through the water of about 15 miles per hour, with *equal* weights or power. And the *additional* velocity from the *increase* of weight (from 72lbs. to 720;) *viz.* 648lbs., is almost precisely the same in each of the three bodies; namely, 16,36 feet in a second.

From which it is evident, that the curve of the line of the bows of ships may undergo many variations without meeting with any difference in the resistance from the water, *when* sailing at their usual *greatest* rate of velocity; and indeed not a great deal in slow motions.

The advantage in the form of the curve of the bow-line, depends therefore in a small degree upon the rate of velocity at which the ships sail; but the variation in the curve of the lines of the bow-end is not so important a consideration, with a view to lessening the resistance of the body in passing

TABLE X.

EXHIBITING the difference in the velocity of bodies, with different formed bow-ends, when acted upon or forced through the water with equal weight or power; and when impelled by double, triple, and quadruple increase of those weights or powers: the bodies being moved at different velocities, at six feet below the surface of the water. Each of the three bodies have one superficial foot area of surface of resistance of midship-section; having the same midship body, and the same tapering stern-ends; and the same length of bow-end; but one bow-end being formed with a straight line, another with a small curve, and the other with a full curve.

Increase of weight.	Weight.	*Small Curve.* Velocity, feet per second.	Increased rate of velocity.	Additional velocity, feet per second.	*Straight Line.* Velocity, feet per second.	Increased rate of velocity.	Additional velocity, feet per second.	*Full Curve.* Velocity, feet per second.	Increased rate of velocity.	Additional velocity, feet per second.
	lbs.	Ft. dec. pts.		Ft.	Ft. dec. pts.		Ft.	Ft. dec. pts.		Ft.
Double	12	3,93	1 37/100	1,46	3,88	1 37/100	1,44	3,85	1 37/100	1,43
	24	5,39			5,33			5,28		
	36	6,47	do.	2,39	6,41	do.	2,39	6,36	do.	2,38
	72	8,86			8,08			8,74		
	48	7,39	do.	2,72	7,31	do.	2,72	7,26	do.	2,71
	96	10,10			10,04			9,98		
	60	8,86	do.	3,01	8,10	do.	3,02	8,04	do.	3,00
	120	11,17			11,12			11,05		
Triple	12	3,93	1 64/100	2,54	3,88	1 65/100	2,53	3,85	1 65/100	2,51
	36	6,47			6,41			6,36		
	24	5,39	do.	3,47	5,33	do.	3,47	5,28	do.	3,46
	72	8,86			8,80			8,74		
Four times	12	3,93	1 87/100	3,44	3,88	1 88/100	3,43	3,85	1 88/100	3,41
	48	7,37			7,31			7,26		
	24	5,39	do.	4,71	5,33	do.	4,71	5,28	do.	4,69
	96	10,10			10,04			9,98		

through the water, as that of contracting the area of the surface of resistance of the midship (bend) section: by adding a little to the fullness of the curve of the bow-end, more capacity or bulk is certainly obtained, and less bulk therefore required at the midship part; but nothing operates so considerably in augmenting the capacity, with a view to contracting the area of the midship-section, as adding to the length of the midship-body; this should be done to the utmost degree of proportion. The area of resistance of the midship-section, should be contracted as much as possible; by obtaining capacity from increasing the length of midship-body, and the curves of the lines of the bow-end at every depth, should be formed to divide the water with the utmost ease and facility at every velocity.

The bow-end formed by a small curve, obtains rather more velocity than that with a straight line, when moving at any rate under 13 miles an hour; about $\frac{1}{200}$ part more at $6\frac{1}{2}$ miles per hour; and they both obtain the velocity of 15 miles per hour, with the same weight or power. The small curve obtains, with the same weight, still rather more velocity than the full curve, when moving at any rate under 15 miles per hour; about $\frac{1}{90}$ part, at $6\frac{1}{2}$ miles per hour: but all three bodies obtain the velocity of 15 miles per hour, with the same weight or power. As, therefore, the body with a small curve at the bow-end, obtains the greatest velocity in slow motions, and as much velocity also as the other two, when impelled through the water at the rate of 15 miles per hour (which is as fast as ships ever sail;) the small curve should be preferred at the bow-end, at the depth of six feet below the surface of the water.

In rapid velocities it appears, that the full curve meets with no more resistance than the small curve: and as the resistance of the water increases with its depth, and the full curve bow-end obtains an increasing advantage as the velocity increases; and in overcoming greater resistances, it would appear, that the curve of the lines of the bow-end can be made a little fuller at greater depths, than in six feet depth in water, without any additional impediment to velocity; and moreover, with an advantage to the capacity.

The most proper form of the curves of the lines of the bow-end of ships depends, first, upon the rate of the velocity at which the ship is required to sail, or for what purpose she is intended; if for burthen, or for despatch. Secondly, to the depth, at which that part of the bow will be immersed in water, where the line is intended to represent. Thirdly, on the direction of that line along the bow-end; whether it is to describe a level line, a diagonal line, or a perpendicular line. The direction of these lines should be the same, as the direction in which the bow naturally strikes the water in dividing it to let the ship pass through. The action of the water is always at right angles, or directly square or flat, against the surface of the different parts of the bow, when the body passes through the water. The power of the resistance acts in the same manner against all the different parts of the bow; and the bow being curving, curves the action of the water to vary in its direction at every part. The more the direction of the curve is opposed against the line of motion, or that of the direction of the ship through the water, the greater is the resistance which it meets with; hence, the curve of the line at the extremity of the bow, meets with greater resistance there, than it does more toward the midship-part.

The resistance from the water will always yield in that direction in which the line of the bow causes it to be divided the easiest; whether it be a level line, a diagonal line, or a perpendicular line; and according to this position of the form bow, so should be the direction of those lines which are formed to divide the water with the greatest ease. If the form of the bow-end, was to be similar to *Figure* P, described in CHAPTER VIII., to divide the water perpendicularly, then the level line would be the most proper for this purpose; and if the bow-end was similar to *Figure* H, to divide the water horizontally, or slanting flatways, then the perpendicular line would be the most proper. The bows of ships are, however, formed to divide the fluid in a direction between these two extremes of the perpendicular and level; and therefore, the *proper direction* of the curve lines should be obliquely, or *diagonally*; leading up from their stations at the midship section, along the bow, in a similar direction that a broad thin board would naturally take when bent and brought up round the bow; or nearly in the direction of the planks round the bow. The higher those lines are stationed in the midship-section, the more they will naturally tend to a

level direction, owing to the form of the bow; and the lower their stations are at the midship-section, the more they will tend upwards toward the perpendicular, owing to the usual form of the bow of ships; and each line will take a different direction: the flatter the (floor) lower part of the midship-section is, the more the lower diagonal lines will tend upward; and the more perpendicular the (second and third futtocks) midship-section is, just below the surface of the water, the more the upper diagonal lines will incline to a level.

In regard to what part of the curve of the diagonal lines of the bow should round the most, in order to meet with the smallest resistance, and to meet with no more resistance in one part than at another; it is needful first to advert to the form of the upper water-line at the bow, or the line described by the surface of the water, when the ship is in sailing trim.

It is of much importance, that ships should sail well in *light winds*, as well as in brisk gales and strong winds; and, therefore, the curve of the bow should be such, as will answer the best to overcome the resistance of the water in *slow*, as well as in rapid velocities. The body with a bow-end having a small curve (as already observed,) obtains with the same weight, more velocity in slow motions, than the one having a full curve; and equally as much in rapid motions. The bow cannot therefore be made too sharp at, and to the depth of, six feet below the surface of the water, with a view to lessen the resistance at all the different rates of velocities which ships usually sail at: for the length of the line of the bow, upon the half breadth plan of ships, may be extended with advantage in a small curve, to the length of six times the half breadth of the line at the midship-section; even at six feet below the surface of the water, and to a velocity of 15 miles an hour.

As the resistance of water in slow motions is less at the surface, and the small curve has the advantage in overcoming resistance in slow motions, the upper water-line should be as sharp as possible; it cannot well be too sharp for the velocity ships sail at. The greatest length of a ship should be at the upper water-line; not only in order to obtain an acuteness of bow, but on every other consideration, as will be pointed out hereafter; the length of the bow should be particularly extended at the upper water-line as much as possible, somewhat similar to the ancient Trireme, described by Bafins, Scaffer, and others:

the stem above should not rake or project beyond that. The weight of the extremity of the bow, and of the bowsprit, ought, if possible, to be brought within, or nearer, toward the midship section. The stem should, however, rake below the upper water-line, or incline under, in a direction towards the midships, as much as about half the breadth of the ship. The nearer the upper water-line approaches toward the extremity of the bow (or the stem), the straighter should be the curve; it should be quite straight near the stem (but not the *least hollow*; and a little rounding, and more and more as it approaches toward the midship part.

It has been observed, that the resistance of water increases with its depth: S S described in CHAP. IX. obtains a velocity of $6\frac{1}{4}$ miles per hour, with one fourth less weight or power than SD: and SS obtains a velocity of $6\frac{1}{4}$ miles an hour, with the same weight that gives to SD a velocity of only $5\frac{3}{4}$ miles an hour; and this is owing to the resistance of the water being less at the surface, than at six feet depth, when bodies are moving at a slow rate. The bow-end with a small curve described in TABLE X. obtains more velocity, than the one with a full curve, when acted upon by the same weights in slow motions; or to overcome lesser resistances. The bow-end with a full curve obtains an equal advantage only in great velocities, and in overcoming great resistances; and will overcome the resistance of the water at a velocity of $13\frac{1}{2}$ miles an hour, with the same weight or power as the bow formed with the small curve. Therefore the nearer the diagonal lines approach the surface of the water, the straighter the curve should be, because the resistance lessens; and *as* the lines lead down deeper in the water, so should the curves increase a little more and more in their fulness, because the resistance increases.

The diagonal lines should be straight, a little below where they intersect the upper water-line; and those which lead to the stem below theupper water-line, should be straight *as* they approach towards the stem, and all of them increase a little more and more in their fulness, *as* the lines deepen in the water. By thus straightening the curves toward the extremity of the bow-end, the direction of them there, will have a position to oppose in a less direct manner the resistance of the water than it would otherwise have, if continued in a curve.

CHAPTER XI.

On the Resistance of Water against the Bow-end of Bodies, when not wholly immersed.

ACCORDING to the theory, the direct resistance of several plane or flat surfaces of different area, when forced through the water at the same velocity, will be in proportion to the area, or extent of their respective surfaces.

There is, however, an exception to this law of resistance, when bodies moving in water are *not wholly immersed* (which is the case with ships,) a broader area of flat surface will then meet with more resistance than a narrow one, in proportion to the difference of the breadth, supposing the depth immersed to be the same: for (inasmuch as the water is divided) it yields round the two sides, and under the bottom of the body only; and not being enabled to yield over the upper part of the body, that being out of the water, the water is heaped up against it by the force of the velocity of the body, and highest at the middle of the upper part above the surface; and the broader the surface, the higher the water is thus raised up at the middle; and the resistance is increased in proportion to the extent of the additional area against which the water is thus raised up above its level; and this causes a variation from the common theory. And on this account, logs of wood move faster with a stream than chips, and chips move faster than sawdust, and a lighter or barge faster sideways than endways, &c.

By experiment, the variation is found to be as follows; *viz.*

When the surface is	9	inches, the resistance, by experiment, being	9,	and also	9	by theory.
If the surface is	16	the resistance, by experiment, is	17,53	instead of	16	ditto
ditto	36	ditto	42,75	ditto	36	ditto
ditto	81	ditto	104,73	ditto	81	ditto

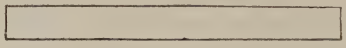
All bodies not wholly immersed, meet with more resistance than if wholly immersed; in consequence of the water being raised above its level at the bow-end by the force of the velocity of the body against it; not only so, but a broader area of flat surface of bow-end meets with more resistance than a narrower one, in proportion to the difference of the breadth, for the reason, and in the proportion before stated. The variation from the theory, may, however, be found to differ at different velocities, and be greater at very great velocities, when the water is forced before the bow-end in a greater degree than divided by it.

PART II.

CHAPTER I.

On the Suction at the Stern-end of Bodies moving in Water.

THAT this subject may be more particularly considered, it will be proper in the first place, to take a view of the effect of the suction on the stern-end of bodies when square, ; as that of the body of this figure.



When this body is moving in water, the pressure of the water against the bow-end will be increased, and its pressure against the stern-end will be diminished in consequence of the motion. Water is so powerful in its effect, that a very small quantity may be made sufficient to support the heaviest bodies; and of course a very small quantity is sufficient to diminish, or even deprive them of their support.

If a floatable body of any weight is put into a container capable of holding water, and the container made exactly to fit and receive the body, a very small quantity of water poured into the container, will be found sufficient to lift and support the body; of course a very small quantity taken from the container, is sufficient to deprive the body of its support; and just so it is with regard to the effect of the pressure of water in a lateral direction.

Now whether a body is caused to forsake the water, or the water to forsake the body, the effect is precisely the same. When, therefore, the body having a square stern-end is moving in the water, the stern-end forsakes the water, and it suffers an instantaneous diminution of the pressure of the water against its stern-end; for the water requires time (however short that time may be) to keep in contact with the stern-end when the body is in motion; and the water must close against it, and with a certain power, before the same pressure can take place, as it obtained when at rest. There must, therefore, be an interval of time between that of the stern-end forsaking the water, and the water coming in contact with it again; and in that interval there must consequently be some space (however small that space may be,) between the stern-end and the closing water; therefore, even in the shortest interval, there will be a tendency to a vacuum between the stern-end and the water, for the atmospheric air is excluded from occupying such space under water. The space between the stern-end and the closing water, becomes subject, therefore, to the whole pressure of the atmosphere; and this pressure must be sustained by the body in its motion; as by its motion, this tendency to a vacuum at the stern-end is created; and it is so sustained by the area of the resistance of the body, in a similar manner as the pressure of the atmosphere is sustained by the sucker of a pump, when drawing up water.

Now there is not only the pressure of the atmosphere operating to fill up any vacuum at the stern-end, but there is also the whole weight of the water above in addition to it; and these combined, are so powerful, that (as will be shewn presently) it is hardly possible there can be any thing like a vacuum, excepting at prodigious velocities; but the space is filled with water, attracted to the stern-end from the surrounding fluid; and this dead water accompanies the body in its motion, continually occupying the space between the stern-end and the closing fluid. This effect of the atmosphere on bodies moving in water, is by some called the minus pressure; but as mariners and practical men usually call it the *suction*, it will be more generally understood by that appellation, and for that reason the most preferable term, although strictly speaking it may not be allowable.

The pressure of the atmosphere on the surface of the water is equal to the

weight of a column of water 34 feet high; it follows, therefore, that there is double the pressure on a void at 34 feet depth in water, as there is close below the surface of the water; at 17 feet depth one and a half as much; and in that proportion at intermediate depths; and the pressure close below the surface, is half as much as at 34 feet depth. But although the pressure of the water at 34 feet depth, arising from its own weight, is 34 times as great as at 1 foot depth, yet the suction of bodies being caused by the pressure of the atmosphere alone, is not in the least altered or diminished, when bodies with square stern-ends are moved at different depths in water; since the pressure of the water arising from its own weight, is always the same at the bow-end of the body, as at the stern-end; let the body be immersed at any depth in water; and when the body has motion, there must always be the same diminution of pressure at the stern-end, at every depth; and this is confirmed by experiment: for it is found, that when bodies are moving at six feet depth in water, there is the same suction as when moving close below the surface; and when moving even at the slowest rate of velocity there is a suction, notwithstanding the velocity of the water in closing on the stern-end, is many times greater than the velocity of the body through the water: the suction is caused by the pressure of the atmosphere alone.

The suction commences at the slowest rate of velocity, and increases with increase of velocity; there is always a tendency to a void at the stern-end of bodies, even at the slowest rate of velocity. The pressure of the atmosphere on the sucker of a pump, commences as soon as the water begins to be raised in the pump; and it increases the higher the water is raised, till it gets up to 34 feet high; if the water is raised 34 feet high, the suction is then equal to the whole pressure of the atmosphere; if drawn only 1 foot high, equal to $\frac{1}{34}$ part of that weight only. And thus the greater the velocity of a body through the water, the greater is the power of the atmosphere on the area of resistance, arising from the greater loss of pressure at the stern-end by the velocity, and the greater the suction: for instance; the suction of a body with a square stern-end, is found to be equal to the weight of 11b. to every superficial foot of area of resistance, when moving through the water at a

velocity of $2\frac{1}{2}$ feet per second, or at $1\frac{1}{2}$ mile per hour; and equal to 68lbs., at a velocity of $22\frac{1}{2}$ feet per second, or $13\frac{1}{2}$ miles per hour.

The continual efforts of the water to close on the stern-end of bodies when moving therein, arises from the *velocity* of the water, occasioned by its weight and fluidity; it is the power of gravity acting on the weight of the water; the upper part, naturally gravitating on the lower part, forces, by its fluidity, in every direction, with equal velocity in every direction, whether laterally, horizontally, obliquely, or perpendicularly. And the *pressure* of water, owing to its fluidity, is equal in every direction; the upward pressure, the downward pressure, and the lateral (or sideway) pressure, is always equal and alike at equal depths.

It is still further to be observed, that the pressure of water, arising from its own weight, increases in proportion to its depth; that is to say, it has ten times as much pressure or weight at 10 feet depth, as at 1 foot depth; and, therefore, the pressure at any particular depth depends on the height or weight of the water above such depth. The pressure of water, from its weight, increasing with its depth, causes the velocity of the water, in closing on the stern-end of bodies, to be greater at greater depths; but then, the velocity does not increase in the proportion that the pressure or weight increases with the depth; for although the pressure of water from its own weight, is four times as much at 40 feet depth, as it is at 10 feet depth, yet the velocity of water is not four times as great, but only twice as great: the velocity increases only double with four times the depth of water, and triple with nine times the depth. In order to find the velocity of water in closing on the stern-end of bodies at any depth, multiply the depth by $64\frac{1}{3}$, and the square root of the product is the velocity; for instance, if the velocity of water was required to be known at 6 feet depth, then 6 times $64\frac{1}{3}$ is 386; and the nearest square root of 386 is 19, the velocity sought for; 19 times 19 is 361. The accumulated hydraulic *pressure*, by which a vein of water is forced through an orifice in the bottom or side of a container, is equal to the weight of a column of water, having for its base the section of the vein, and *twice* the fall productive of the velocity of afflux for its height, but the

velocity of a spouting fluid that of falling *once* the height; *viz.* the height from the surface of the fluid.

The velocity of water in closing, after being divided by a moving body, increases with its depth; and therefore, a body may be moving at a certain depth in water, and the water not have sufficient time to close; whereas, if moving at a greater depth, it would have a sufficient time to close; for the greater the depth of the water, the greater is the velocity with which it moves and exerts itself toward the stern-end of bodies in motion. But the velocity of the water in closing on a body with a *square* stern-end, by no means alters the suction; the water may even close with double the velocity which the body has through the water, and the suction remain: for instance, the velocity of the water at 6 feet depth, is 19 feet per second; and the body with a square stern-end, moving at that depth in water, with only half the velocity ($9\frac{1}{2}$ feet per second,) has still a suction equal to the weight of $11\frac{1}{4}$lbs.; and when moving even at 19 feet per second, has a suction equal in weight to 53lbs., as may be seen in TABLE XI. The filling up the void in this case, is not the action of the closing water, but that of the pressure of the atmosphere on the area of resistance, which causes the stern-end to draw to it a body of dead water to fill up the void, and which accompanies the body in its motion; and against *this dead water* the fluid closes.

The velocity of this body must be prodigious, before anything like a vacuum could be made at the stern-end; when moving at a velocity of $9\frac{1}{2}$ feet per second, the suction is equal to $11\frac{1}{4}$lbs. weight, to a superficial foot of area of resistance; but before any vacuum could be formed, the suction must be equal to a column of water of one foot base and 40 feet high. The pressure of the atmosphere being equal to the weight of a column of water 34 feet high, and the pressure of the water at 6 feet depth to 6 feet more, and the weight of a cubic foot of water being 64lbs., the weight of 40 cubic feet must be 2560lbs.; therefore the suction on one superficial foot of area of resistance, must be equal to 2560lbs. weight, before a vacuum could be made at six feet depth in water; and thus if one end of a long tube

be immersed in water, no void could be formed in the tube till after the water was raised 34 feet in it. When the velocity of this body is 19 feet per second, the suction is equal in weight to 53 lbs.; still the pressure being equal to 2560 lbs., there could be no vacuum; there would be a body of dead water attracted to the stern-end by the pressure of the atmosphere, and superincumbent fluid on the area of resistance; and the suction on one foot area of resistance being equal to 53 lbs., and a cubic foot of water 64 lbs.; it is clear the body of dead water can only be $\frac{53}{64}$ of a foot thick, and only $\frac{53}{2560}$ parts of the weight of the atmosphere and superincumbent fluid.

Now, although the velocity of the body is 19 feet per second, and the velocity of the water in closing is the very same (19 feet per second), yet there is a suction equal to 53 lbs. weight; and this arises from the additional pressure against the midship-section, caused by the suction: the velocity of the water in closing arises from its pressure and weight alone; but the suction arises from the pressure of the atmosphere, which is much greater, and of more instantaneous and powerful effect in this case.

Hitherto, the effect of the suction has been considered on a body with a square stern-end. Now, supposing another body having one foot area of resistance, and having a tapering stern-end, similar to this *Figure*

and moved through the water at six feet depth:

Now as the tapering line of the stern-end can never be parallel with the direction of the motion of the body, it would appear, that the suction would always be the same, inasmuch as it is occasioned by the pressure of the atmosphere on the area of resistance, which still remains the same, let the stern-end taper ever so much; yet it is certain, that the suction may be lessened by lengthening the taper of the stern-end; and it is also certain, that it may be wholly done away by lengthening the stern-end sufficiently; and the causes of this, arises from the action of the closing water, from the

taper of the stern-end, presenting the dead water to the action of the closing fluid.

When the stern-end is of such a length as that the suction is lessened only, the closing water acts with a partial force upon the dead water, so as to lessen its attraction to the body by moving it; the attracted water in consequence accompanies the body only in a partial degree of its velocity; and the attraction being lessened, the effect of the suction is also lessened, for the weight of the drag of this water is diminished; and the velocity with which the attracted water accompanies the body, depends on the power of the action of the closing water against it; and this power depends on the length of the taper of the stern-end. When the stern-end is of such a length that the effect of the suction wholly ceases, two causes operate; first, the power of the closing water against the attracted water is so great, as to assimilate it to itself, and the attracted water has no motion whatever with the body; the attraction is counteracted: and, secondly, the closing water acts with a pressure or power on the stern-end, by impinging along it (similar to the pressure of the wind on the sails of a ship when close hauled in going to windward; or in other words, when placed in an oblique direction from the wind,) and when this pressure of the closing water on the stern-end, becomes equal to the pressure of the water against the stern-end when at rest, then all effect of suction ceases.

The water attracted to the tapering stern-end of bodies, can never accompany them with the velocity of the bodies, excepting when the closing water cannot, by its own force and velocity, move it; and it is difficult to conceive, that the attracted water very usually does so, on account of the power and velocity of the closing fluid; for it is found by experience, that the copper, on the after bodies of ships, wears away by the action of the water (though not so fast as at other parts of the bottoms of ships,) and this could not happen, if the water attracted to the stern-end, accompanied the vessel in its full motion.—Some have supposed there is continually an atmosphere of water carried by a body in its motion through the water.

Supposing a body moving through water to be 30 feet wide at the midship-section, and the length from the midship-section to the extremity of the stern-end to be 45 feet; and that the stern-end tapered to a point, the water will then have to move in closing on the stern-end, 15 feet on each side, while the body moves forward 45 feet; and supposing also, that the water would, by its natural velocity, close on the body when moving 45 feet per second; if, therefore, the body moved $22\frac{1}{2}$ feet per second, the water would only have to close $7\frac{1}{2}$ feet on each side; and this it would do in half the time; *viz.* half a second; it follows, therefore, that the stern-end would be longer than necessary for the water to close upon it, when the body is moving at $22\frac{1}{2}$ feet per second, because the water closes on it in half the time that is required of it to do; whereas, when the body is moving 45 feet per second, the water has only just sufficient time to close, and therefore the stern-end is not too long with this view, at that velocity; it is evident therefore, that a stern-end may be long enough for a certain velocity, and longer than needful at slower velocities; and also, that it may be long enough at slow velocities, and not long enough for greater velocities. Consequently, the due and proper length of the taper of a stern-end, with the view to the water closing against it, depends in one case on the rate of the velocity of the body through the water.

The velocity of the water in closing increases with its depth; it closes on a stern-end in half the time at twelve feet depth, that it would do at three feet depth; and therefore, the taper of the stern-end of a body requires to be only half the length at 12 feet depth in water, that it does at 3 feet depth. Consequently, the due and proper length of the stern-end of bodies, to enable the water to close against them, depends on the depth at which the bodies are immersed, as well as on the rate of the velocity of the body through the water.

Hence in regard to the closure of water on the stern-ends of bodies, when moving through it with velocity, it appears, that water closes in every direction with the same velocity and in the same time at equal depths; and that it closes with greater velocity at greater depths, than at lesser depths, according to the height or weight of the water above such depth: and that the velocity of water in closing at any particular depth is invariable and

determined, let the velocity of a body moving at such particular depth be ever so great.

The power of the suction must always act and depend on the area of the midship-section of bodies; and it is lessened in the first place, by the tapering stern-end presenting the attracted water to the action of the closing fluid, which lessens its attraction to the stern-end: and in the next place, by the lengthening the stern-end the attraction is entirely counteracted, and the closing fluid acts with a force or pressure on the taper, similar to the action of the wind impinging on the sails of a ship when sailing to windward; and this force of the closing water, in-as-much as it overcomes the attraction, and affords a sufficient pressure against the stern-end, must be equal to a power that would impel the vessel forward, as much as the suction would otherwise retard the velocity of the body. The power of the attraction of the dead water to the tapering stern-end, is at right angles with the direction of the taper; the power of the closing water to remove it, is in the direction of the taper of the stern-end; and the power of the closing water in affording a due pressure or support, is at right angles with the taper.

The direction of the efforts of water in filling up a vacated space, is every way, and every way with the same power; upwards, downwards, and sideways, in every direction alike; when, therefore, a body with a tapering stern-end is moving through water, and wholly immersed therein, the water, in its efforts to close on the stern-end, has a motion to follow the body, to pass the body, and to move sideways against the body, to press upward, and to press downward; its force in every direction is alike, and always with a determined velocity. But when the body moves through the water, the efforts of the water in its closure by following the body must be lessened by the body moving from it: whereas, the efforts of the water in closing in the direction to pass the body, being met by the motion of the body, must be increased thereby: the pressure of the water upwards and downwards, and its efforts in closing sideways against the stern-end, is not at all affected by the motion of the body; for it always closes on the body in the same time, and with the same power in these directions, let the velocity of the body be what it

may. It is therefore clear, that the direction of the efforts of the water in closing against the tapering stern-end of bodies, is chiefly in a direction sideways, and still more particularly so in a direction to pass the body, owing to its meeting the closing water in that direction in its motion.

The direction of the efforts of the water in closing on the stern-end, is, therefore, between that of passing the body, and that of moving sideways against the body, in a mean direction between the two, in a similar direction with the line of the tapering stern-end of bodies. The faster the body is moved through the water, the more the line of the direction of the water's efforts in closing on the stern-end, becomes toward a parallel with the direction of the line of motion; and therefore the longer the stern-end is required to be in order to escape suction. And the slower the body is moved through the water, the more the line of direction of the water's efforts in closing on the stern-end, becomes towards a right angle with the direction of the line of motion, or its efforts becomes more sideways; and therefore the shorter the stern-end is required to be, in order to escape the suction.

When the direction of the line of the tapering stern-end is within (or more inclined sideways than) the line of direction of the water's efforts in closing; the suction is in no way diminished; but equal to what it would be if the stern-end was square, or had no taper at all. When the direction of the line of the tapering stern-end is such, that the closing water impinges against the attracted water, without a sufficient power either to move it, or lessen its quantity; such a taper of stern-end causes a greater impediment to velocity, than if there were no taper at all, or as if the stern-end was square; and this is owing to there being, in addition to the suction, a friction, arising from the closing water moving against the attracted water; and which (as will be seen by and by,) is confirmed by experiment. When the direction of the line of the tapering stern-end, is without (or more in the direction of the line of motion than) the line of direction of the water's efforts in closing; the attracted water is presented to the action of the closing fluid; and it removes the attracted water either in part, or wholly, according to the difference in their direction; and the

greater the difference is, the more powerfully the closing water acts upon the attracted water. The direction of the closing water, forming an angle with the direction of the tapering line of the stern-end impinges along against it, and acts upon the attracted water to remove it. And when the tapering stern-end is so long as that the closing water acts upon it with its greatest power, the attracted water is not only removed, but the closing water acts with a force, or pressure, against the tapering stern-end; and when this force and the power of its pressure is equal to the power of the pressure against the midship-section, arising from the suction; of course every impediment to the velocity, arising from the suction, ceases.

The precise angle which the line of direction of the closing water should make with the line of direction of the tapering stern-end, for the closing water to operate with its greatest effect in doing away the suction, depends, first, upon the rate of the velocity of the body through the water; and, secondly, upon the depth at which the body is moved in the water. The velocity of the body, and the depth of water being determined, the angle should then be regulated, so that the closing water should, by impinging along the stern-end act with its greatest power, upon a principle somewhat similar to the setting of a sail properly, for the wind to have its greatest effect in forcing a ship forward when sailing to-windward.

Some have affirmed, that the suction of stern-ends of the same figure, may be diminished by increasing the length of the middle part of a body, even in some cases reduced to one fourth; it is, however, difficult to conceive it can have any material effect, and the most recent experiments prove, that it has not; and further, that in almost all cases, the lengthening the midship-part, even impedes the velocity; and that as much as by the impediment from the increase of the friction on the part lengthened.

From what has been premised, it will appear, that in addition to resistance from the pure inertia of the water, there is that of the suction; for if the stern-end of a body is not formed to admit the water to close against it, and with a certain force, while the vessel is in motion, the midship-part, by the

pressure of the atmosphere, will have, in consequence, to sustain continually (exclusive of the resistance of the water against the fore-part of the body to the midship-section), a pressure equal at least to the weight of a body of water, of such bulk as fills the space between the stern-end and the closing fluid; and which space is continually filled with water, drawn after the body: for the pressure of the atmosphere prevents any possibility of a vacuum, at any velocities at which ships usually sail.

And this water, which is attracted to the stern-end of a body, being dragged along with it, the closing fluid in some cases takes its course against it as before described, and it is then dragged in opposition to the tenacity and friction of the closing water; it becomes in that case an addition to the resistance, from two causes: first, from its weight; and, secondly, from its tenacity and friction against the closing fluid. The suction, therefore, separates this attracted water from that which the body passes through, and it also draws it against the closing fluid; and there is, besides, a natural attraction of the water to the body.

Thus, therefore, the stern-end of bodies, in passing through water, has the impediment to velocity, of the attraction of the water to the body from the suction: of the natural attraction of the water to the body; of the tenacity and friction of the closing fluid against the attracted water; and, in some instances, of the friction of the attracted water against the body; namely, in those cases where the attracted water is moved only a little by the closing fluid.

Under these different circumstances, the suction is sustained by an additional pressure against the midship-section of bodies; and the power of this pressure must always depend on the area of the midship-section, on the form of the stern-end of the body, and on the velocity of the body; for, whatever the suction may be, it increases very powerfully with increase of velocity. And this additional pressure on the midship-section must retard the velocity of a body, as much as a force equal to such pressure would increase the velocity if applied to impel the body forward. A power must be required to separate the attracted water from that which the body passes through, likewise to

draw it along with the body, and also to move it against the closing fluid; which power must be in addition to that required to overcome the resistance, independent of the suction.

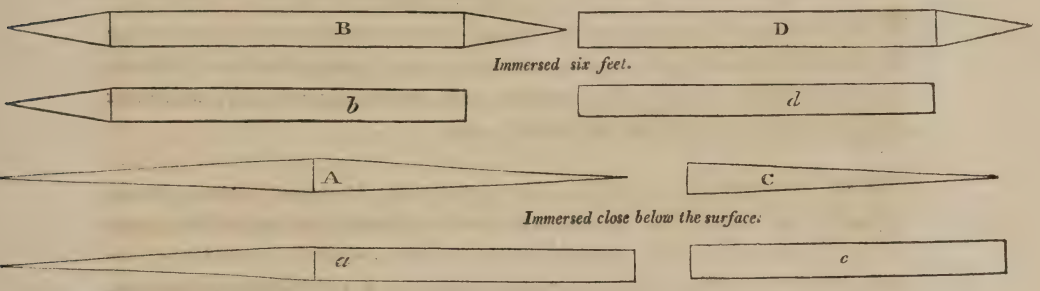
By referring to TABLE XI. the impediment to the velocity will be more particularly seen, as it relates to bodies with square stern-ends. The body *c*, with a square stern-end, having one foot of area of resistance [or of mid-ship-section], requires $2\frac{1}{8}$ lbs. weight, when moving at the rate of $2\frac{1}{2}$ miles per hour, and 12 lbs. weight when moving at the rate of $5\frac{1}{4}$ miles per hour; in order to overcome the impediment to the velocity, arising from the suction alone: and the bodies, *a*, *b*, and *d*, the same.

The suction is ascertained as follows:—The bodies, A, B, C, and D, having tapering stern-ends, and of a length to create no suction whatever at those velocities: and A *a*, B *b*, C *c*, and D *d*, having respectively the same bow-ends and midship-sections, and *a*, *b*, *c*, *d*, having square stern-ends; it follows, that whatever difference there is in the weight required to give *a* the same velocity as A; and *b*, the same as B; and *c*, the same as C; and *d*, the same velocity as D; must solely arise from the difference in the stern-ends of each two respectively: and the weight which the square stern-ends require, more than the bodies with tapering stern-ends, to obtain the same velocity, is the weight or power o the suction.

TABLE XI.

SHEWING the impediment to velocity from the *suction*, and the power or weight required to sustain the additional pressure on the midship-section arising therefrom: the bodies described having one foot area of surface of midship-section, and moving at different velocities, both close below the surface, and at six feet below the surface of the water; and having sharp and flat bow-ends, and flat or square stern-ends.

Bodies with *sharp* bow-ends and square stern-ends. Bodies with flat bow-ends and square stern-ends.



Velocity.		Suction of *a*, moving close below the surface.	Suction of *b*, moving six feet below the surface.	Suction of *c*, moving close below the surface.	Suction of *d*, moving six feet below the surface.
Miles per hour.	Feet per second.				
	ft. dec. pts.	lbs. weight.	lbs. weight.	lbs. weight.	lbs. weight.
1 full	1,84				0½
	2,26		0¾		
1½ full	2,63				1
	3,28		1 5/16		
2¼ bare	3,76				2
	4,10			2⅛	
	4,43	3			
2¾	4,64				2¾
	4,75		3⅛		
3	5,07	4¼			
3¼ bare	5,39				3½
	5,59	5½			
	5,84			7	
	5,90		4⅝		
3½	5,91	7¼			
	6,44	8			
4	6,76	8¾			
	6,88		6⅝		
	7,46			10	
4⅛	7,63	9			
4½ full	7,71				7¾
	7,75		8⅛		
	7,79	9½			
	8,54		10⅛		
5¼ bare	8,66				8¾
	8,80	12			
	8,86			12	
5¾ bare	9,52				11¼
	9,96		14 1/16		
6¾ bare	11,22		17		

CHAPTER II.

On the Increase of the Suction of Bodies with Square Stern-ends, from the Increase of their Velocity through the Water.

THE suction at the stern-end of bodies increases very materially with the increase of the velocity of bodies, and in a greater proportional rate; that is to say, it increases more than double with double the velocity, and more than three times with triple the velocity, &c.

It will be seen in TABLE XII., that the suction at square stern-ends increases at the rate of four times with double increased rate of velocity, and of eight times with triple increased rate of velocity. And it is worthy of remark, that the suction increases with velocity, in a very similar proportion, with the resistance from the water; for the total resistance of bodies impelled through water, increases about four times with double velocity, and nine times with triple velocity. It is also worthy of remark, that the velocity of water, from its pressure, is in a very similar proportion; thus, it requires four times the pressure or depth to give double velocity to water, and nine times the depth to give to it triple velocity.

It appears further in TABLE XII., that the form of the bow-end does not make any variation of consequence in the proportional increased rate of suction, from the increased rate of velocity.

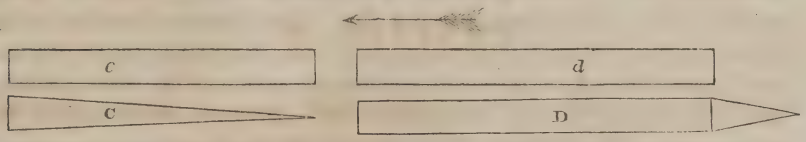
The proportional increased rate of suction, from increased rate of velocity, is much the same at six feet depth, as it is nearer the surface of the water.

The *velocity* of the water, in closing against a *square* stern-end, does not diminish the suction; the velocity of the water, inclosing at six feet depth,

TABLE XII.

EXHIBITING in what rate of proportion the suction increases, when bodies are moved at double and triple rate of velocity.

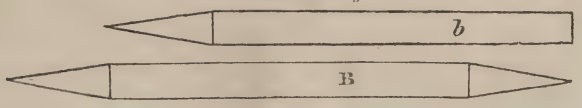
Flat bow-ends and square stern-ends.



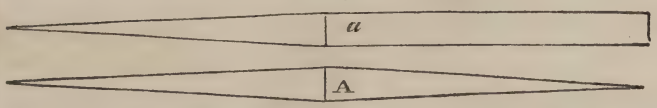
Increased rate of velocity.	Velocities, feet per second.	When moving close below the surface of the water. Weight required to overcome the suction of C.	When moving close below the surface of the water. Increased proportion.	When moving at six feet below the surface of the water. Weight required to overcome the suction of *d*.	When moving at six feet below the surface of the water. Increased proportion.
	ft.dec.pts.	lbs.		lbs.	
Double	1,84..	.....	.....	.... $0\frac{1}{2}$	.. four times.
	3,76..	.....	.....	 2	
	2,63..	.....	.....	.... 1	.. near four times.
	5,39..	.....	.....	.... $3\frac{3}{4}$	
	4,10 ..	.... $2\frac{1}{3}$	.. full five times.		
	8,86..	 12			
	4,64..	.....	.....	.... $2\frac{1}{4}$	.. four times.
	9,52..	.....	.....	.... $11\frac{1}{2}$	
Triple ..	1,84..	.....	.....	.... $0\frac{1}{8}$	.. seven times.
	5,39..	.....	.....	.... $3\frac{3}{4}$	

Sharp bow-ends and square stern-ends.

Immersed six feet.



Immersed close below the surface.



		Moving close below the surface.		*Moving at six feet depth.*	
Double	2,26..	.....	.....	.... $0\frac{3}{4}$	.. four times.
	4,75..	.....	.....	.... $3\frac{1}{2}$	
	3,28..	.....	.....	.... $1\frac{6}{10}$	.. four times.
	6,88..	.....	.....	.... $6\frac{4}{5}$	
	4,43..	.... 3	.. four times.		
	8,80..	 12			
	4,75..	.....	.....	.... $3\frac{1}{2}$	.. full four times.
	9,96..	.....	.....	.... $14\frac{3}{10}$	
	5,90..	.... $4\frac{4}{5}$	.. near four times.		
	11,22..	 17			
Triple	2,26..	.....	.....	.... $0\frac{3}{4}$	.. eight times.
	6,88..	.....	.....	... $6\frac{4}{5}$	
	3,28..	.....	.....	.... $1\frac{6}{10}$	.. nine times.
	9,96..	.....	.....	.... $14\frac{3}{10}$	

being 19 feet per second, it must overtake the body immersed at that depth, when moving at any less velocity than 19 feet per second; and if the suction were owing to the water's not closing against the stern-end, there could be no suction until the body moved at a greater velocity than 19 feet per second.—But it will be seen in TABLE XII., that there is a suction at that depth, even at the slowest velocity; and, also, that there is much the same suction at six feet depth as at close below the surface of the water, although the water closes with more than double the rapidity at six feet depth, than at just below the surface. The suction also increases with increase of velocity, as much at one depth as at another.

The proportional increased rate of suction, from increased rate of velocity, varies according to the length of the tapering of the stern-ends, as will be pointed out hereafter.

CHAPTER III.

On the Impediment to the Velocity of Bodies with Square-ends, arising from the Suction.

IT is the common received opinion, that the resistance with which a plane surface meets when opposed directly to a fluid, is equal to the weight of a column of the same fluid, whose base is of similar dimensions with the surface struck, and whose altitude is the same as that from which a body must fall, to acquire an equal degree of velocity with the fluid. This opinion appears not generally correct, as it respects bodies moving in water; since the pressure of the water against the midship-section of bodies, and in consequence the resistance, and the velocity of bodies, is affected in a material degree by the form of the stern-end; for a body with a square stern-end is subject to the effect of suction, and to the impediment to velocity therefrom; whereas, a body with a long tapering stern-end escapes it altogether, and obtains greater velocity in consequence.

The additional weight or power required to give that velocity to bodies which is lost, in consequence of the suction, when compared with the whole weight required to give velocity to such bodies, is very considerable, as will be seen by referring to TABLE XIII.

Bodies with flat or square bow-ends, and square stern-ends, when moving through water by a certain power or weight close below its surface, require $\frac{1}{8}$ of that weight, in consequence of the suction of the stern-end; and when moving at six feet depth in water, $\frac{1}{14}$ part of that weight, in consequence of the suction. And bodies with sharp bow-ends and square stern-ends, when moving through the water by a certain power or weight close below the surface, require $\frac{1}{7}$ of that weight, in consequence of the suction at the

TABLE XIII.

THE additional weight or power required, in consequence of the suction at the stern-end of bodies; compared with the whole weight required, to give velocity to bodies: the bodies having one foot area of surface of resistance, moving at different velocities, both close below the surface, and at six feet below the surface of the water.

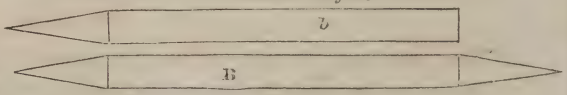
Flat bow-ends and square stern-ends.

Immersed close below the surface. *Immersed six feet.*

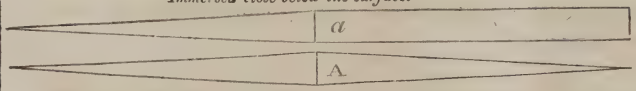
Velocities, feet per second.	Moving close below the surface.			Moving at six feet depth.		
	Whole weight to give velocity.	Weight to overcome the suction.	Proportional difference.	Whole weight to give velocity.	Weight to overcome the suction.	Proportional difference.
ft. dec. pts.	lbs.	lbs.	part.	lbs.	lbs.	part.
1,84	....	.....	.....	.... $6\frac{1}{2}$	$0\frac{1}{2}$	$\frac{1}{13}$
2,63	....	.....	.....	 13	1	$\frac{1}{13}$
3,76	.....	.....	.....	 26	2	$\frac{1}{13}$
4,10	.... $17\frac{1}{8}$	$2\frac{1}{8}$	$\frac{1}{8}$			
4,64	.....	.....	.....	.... $38\frac{3}{4}$	$2\frac{3}{4}$	$\frac{1}{14}$
5,39	.....	.....	.....	.... $51\frac{1}{4}$	$3\frac{1}{4}$	$\frac{1}{14}$
5,84	.... $39\frac{1}{2}$	7	$\frac{1}{6}$			
7,46	.... $71\frac{3}{4}$	10	$\frac{1}{7}$			
7,71	.....	.....	.....	.... $103\frac{3}{4}$	$7\frac{3}{4}$	$\frac{1}{13}$
8,66	.....	....	.....	 129	$8\frac{1}{4}$	$\frac{1}{14}$
8,86	 105	12	$\frac{1}{9}$			
9,52	.....	.....	.....	.... $155\frac{1}{4}$	$11\frac{1}{4}$	$\frac{1}{14}$

Sharp bow-ends and square stern-ends.

Immersed six feet.



Immersed close below the surface.



2,26	.....	.....	.....	.... $6\frac{2}{5}$	$0\frac{2}{5}$	$\frac{1}{6}$
3,28	.....	.....	.....	.... $13\frac{6}{15}$	$1\frac{6}{15}$	$\frac{1}{8}$
4,43	 9	3	$\frac{10}{30}$			
4,75	.....	.....	.....	.... $27\frac{1}{5}$	$3\frac{1}{5}$	$\frac{1}{8}$
5,07 ...	 10	$4\frac{2}{4}$	$\frac{14}{30}$			
5,59	.... $11\frac{1}{2}$	$5\frac{1}{2}$	$\frac{14}{30}$			
5,90	.....	.....	.....	.... $40\frac{4}{5}$	$4\frac{4}{5}$	$\frac{1}{9}$
5,91	... 15	$7\frac{1}{4}$	$\frac{14}{30}$			
6,44	 15	8	$\frac{14}{30}$			
6,76	.... $18\frac{1}{2}$	$8\frac{3}{4}$	$\frac{14}{30}$			
6,88	.....	.....	.....	.... $54\frac{2}{5}$	$6\frac{2}{5}$	$\frac{1}{8}$
7,63	 23	9	$\frac{12}{30}$			
7,75	....	.....	.....	.... $68\frac{1}{7}$	$8\frac{1}{7}$	$\frac{1}{8}$
7,79	 30	$9\frac{1}{2}$	$\frac{9}{30}$			
8,54	.....	.....	.....	$82\frac{1}{6}$	$10\frac{1}{6}$	$\frac{1}{8}$
8,80	 30	12	$\frac{12}{30}$			
9,96 ...	.....	....	.....	.... $110\frac{1}{10}$	$14\frac{3}{10}$	$\frac{1}{8}$
9,98	 46					
11,22	.....	.....	.....	 137	17	$\frac{1}{8}$

stern-end; and when moving at six feet depth in water, $\frac{1}{8}$ part of that weight, in consequence of the suction.

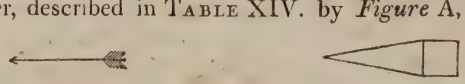
But, it must be observed, that, as the power or weight required, to give the velocities *stated in the* TABLE to these bodies when moving near the surface of the water, is *less* than when they are moving six feet below the surface of the water; and the additional power required, in consequence of the suction, being much the same at each depth; so, in consequence of the aforesaid variation (as will be seen by referring to TABLE XIII.), the additional weight or power required, in consequence of the suction, *compared* with the whole weight to give velocity, is much less in proportion thereto, at six feet depth in water, than at close below the surface: but at such higher velocities than specified in the TABLE, when there is no difference in the resistance of the water, close below the surface, and at six feet depth; the suction bears a like proportion to the resistance at *each* depth.

CHAPTER IV.

On the Suction of Bodies with Tapering Stern-ends of different Lengths of Taper.

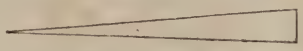
When a body, having a tapering stern-end, is moving through the water; if the stern-end has not a sufficient length of taper to admit the water closing any where with effect against it; the suction, in that case, becomes at least equal to what it would be if the stern-end had no taper, or was square or flat.

The suction may be even greater with too short a length of taper of stern-end, than it would be if there was no taper at all: for the body with an equilateral triangle added to the stern-end, moving *at six feet* below the surface of the water, described in TABLE XIV. by *Figure* A, has more suction than

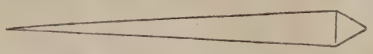


this body with a square stern-end: and the increased rate of the suction of *Figure* A, from increased rate of velocity, is also greater than that of this body with a flat or square stern-end; the difference of the suction also increases, the faster the bodies move in the water. The reason of A having more suction is this: the attracted water at the stern-end of A being in a line with the closing fluid, is drawn against, and in opposition to, the closing fluid; and which is not the case, with respect to this body with a square stern-end.

And, further, two bodies moving *close below* the surface of the water;



this body with a flat stern-end, has less suction than this with an equilateral



triangle added to the stern-end; the attracted water at the triangular stern-

end, being presented to, and subject to the tenacity and friction of the closing fluid, without sufficient power to lessen or move the attracted water; and the triangular stern-end has still a greater degree of suction than the other, as the velocity of the bodies increase.

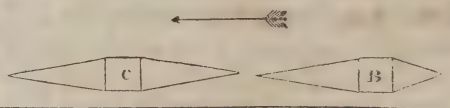
By reference to TABLE XIV. it will be seen, that the suction of the body A, with a short stern-end, one third the length of that of the body C, is about $\frac{1}{7}$ part of the whole weight required to give the velocity. And the suction of the stern-end of the body B, which is only half the length of that of C, is about $\frac{1}{19}$ part of the whole weight required to give the velocity. And the suction of the stern-end of the body A, is near four times as great as that of the stern-end of the body B, at all the different velocities, although the stern-end of B, is only half as long again as that of A; and for this reason; the stern-end of B being more in a direction for the closing fluid to act against it, than the stern-end of the body A: the closing fluid takes away a portion of the attracted water, lessens the quantity drawn after the stern-end of the body B, and diminishes the effect of attraction.

The stern-end of the body C, is in length, three times the breadth of the midship-section, or six times the length of the half breadth, and it obtains small velocities especially; and every rate of velocity under 8 miles (and most likely 10 miles) per hour, with less weight than this body does, which

has a stern-end half as long again; *viz.* nine times the length of the half breadth, (owing to the closing water not acting with its greatest force on such an angle at those velocities; and also to the friction on the increased length of this stern-end, as will be shewn hereafter) which proves that the stern-end of C has no suction at those velocities; and that the angle of the stern-end is in such a direction, that the closing fluid not only acts against it to take away the attracted water, but also to press against the stern-end with the strongest effect, and with a force equal to that loss of pressure, which the stern-end experiences from forsaking the fluid by the motion of the body. At velocities of 12 miles per hour, and upwards, a suction would

TABLE XIV.

IMPEDIMENT to the velocity of bodies, occasioned by the water not closing with its full effect on tapering stern-ends; shewing the difference in the suction, arising from the difference in the length of the stern-ends of bodies, by the difference in the weight, required to give the same velocity to those with tapering stern-ends of different lenths. The bodies described, have the same midship-part, and the same bow-end, and are moved at six feet below the surface of the water.—N. B. C has no suction at those velocities.

Longest stern-end *twice* the length of the shorter stern-end. 					Longest stern-end *three* times the length of the shortest stern-end.			
Velocity.	Weight to give velocity to C.	Weight to give velocity to B.	The difference is the suction of B.	Proportion of the suction of B to the whole weight.	Weight to give velocity to C.	Weight to give velocity to A.	The difference is the suction of A.	Proportion of the suction of A to the whole weight.
Miles per hour.	lbs.	lbs.	lbs.		lbs.	lbs.	lbs.	
$2\frac{1}{2}$	15	$15\frac{4}{5}$	$0\frac{4}{5}$	$\frac{1}{19}$	15	$16\frac{8}{10}$	$1\frac{8}{10}$	$\frac{1}{9}$
3	22	23	1	$\frac{1}{23}$	22	26	4	$\frac{1}{6}$
$3\frac{1}{2}$	31	$32\frac{3}{10}$	$1\frac{3}{10}$	$\frac{1}{25}$	31	36	5	$\frac{1}{7}$
4	41	$43\frac{1}{11}$	$2\frac{1}{11}$	$\frac{1}{20}$	41	48	7	$\frac{1}{7}$
$4\frac{1}{2}$	53	$55\frac{7}{10}$	$2\frac{7}{10}$	$\frac{1}{20}$	53	$62\frac{7}{10}$	$9\frac{7}{10}$	$\frac{1}{6}$
5	66	$69\frac{8}{9}$	$3\frac{8}{9}$	$\frac{1}{18}$	66	79	13	$\frac{1}{6}$
$5\frac{1}{2}$	82	$86\frac{4}{10}$	$4\frac{4}{10}$	$\frac{1}{19}$	82	$96\frac{3}{4}$	$14\frac{3}{4}$	$\frac{1}{6}$
6	99	$104\frac{3}{10}$	$5\frac{3}{10}$	$\frac{1}{19}$	99	$117\frac{2}{10}$	$18\frac{2}{10}$	$\frac{1}{6}$
$6\frac{1}{2}$	117	$123\frac{1}{2}$	$6\frac{1}{2}$	$\frac{1}{19}$	117			

doubtless be created by the stern-end of C; for a stern-end may be long enough for a certain velocity, and too short for a greater velocity; and the greater the velocity, the longer the stern-end is required to be; and the longer stern-end before described having then no suction, would therefore obtain the greatest velocity through the water, with the same weight or power. The water always closes with a certain and determined velocity at any particular depth; and, therefore, when a body is moving at a certain velocity, the water may have time enough to close with full effect on a long stern-end, and not time enough to close with full effect on a shorter stern-end. It is evident, that the stern-end of C, is long enough for velocities under 8 miles per hour, or it would not obtain a greater velocity with the same power, than this body with a longer stern-end.

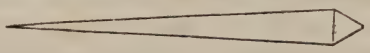
It must be noticed particularly, that as C obtains every rate of velocity, with less weight than either A or B, it follows, that the tapering-line of the stern-end ought not to be shorter than six times the half breadth at the midship-section, at six feet below the surface of the water, at any velocity under ten miles per hour; and further, that it should be more than six times the half-breadth in length at greater velocities.

The velocity and power of the water, in closing against the tapering stern-end of bodies, varies at different depths; it closes quicker at greater depths, than at lesser depths: it follows, that the taper of a stern-end may be long enough at a certain depth, for the closing water to act with its full force against it, and that at lesser depths, it may be too short; that the water may not have time to close against it with its full power. Therefore, the nearer a body is moving toward the surface of the water, the longer the taper of its stern-end is required to be. And further, the more rapidly the body is moved through the water, the longer it is required to be in order to avoid suction, let the body be moved at whatever depth it may. There can be no question, but that with the same weight or power, the body with the longest taper of stern-end must obtain the greatest velocity in rapid motions through the water, when moving at any depth.

It is worthy of observation, and may be seen by referring to Table II.

PART I., where the same bodies are described moving the reverse way; that the suction, arising from the shortness of the stern-end of A, occasions as great an impediment to velocity, as the increase of resistance from the same shortness of bow-end would create: for instance, if the body A were moved with the stern-end foremost, it would obtain a greater velocity with the same weight, than if moved with the bow-end foremost; and the advantage of this fulness or shortness being at the bow-end, increases more and more with increase of velocity. The same occurs with the body B, only with this difference; that the advantages increase but triflingly with increase of velocity.

It may also be observed, that when a body is moved through the water *close below the surface*; a *very great* difference in the fulness or shortness of the two extremities of a body operates differently from the foregoing; for instance, this body having a long sharp bow-end, and a short stern-end,



when moved through the water close below the surface, obtains much more velocity with the same weight, than when moved the reverse way, with the stern-end foremost; and the advantage increases considerably, the faster the body is moved through the water.

The body A, which has a stern-end one foot long on the angle, requires *ten* times more weight to overcome the suction, when moving through the water at the rate of six miles an hour, than when moving at the rate of two and a half miles an hour. The body B, having a stern-end, one foot six inches long, requires *six and a half* times more weight to overcome the suction, when moving six miles an hour, than when moving two and a half miles an hour. Another body having a stern-end *two feet* long (being alike in all other respects to A and B), requires *four and one fifth* times more weight to overcome the suction, when moving at the rate of six miles an hour, than when moving at two and a half miles an hour.

From which it appears, that the *proportional increase* of suction, from increase of velocity, depends on the form of the stern-end, and that it varies

according to the length of the taper of the stern-end of bodies; and that the longer the taper of the stern-end is, the less the suction increases with increase of velocity. And therefore, the suction is not only less with a longer taper of stern-end than with a shorter one, at any rate of velocity; but it also increases in a less proportion with increased rate of velocity with a longer taper of stern-end, than with a shorter one. And as, therefore, the increase of suction from double increase of velocity, varies thus according to the length of the taper of the stern-end; so does the proportion of the weight or power required to overcome the suction created by double the velocity vary also; and therefore, the whole weight required to give double the velocity to a body, must also in some measure vary, according to the length of the taper of the stern-end; since the whole weight to give velocity, acts in part to overcome the suction. And hence arises one of the causes, why the increase of the resistance of water against bodies, when moved at any increased rate of velocity, does not accord with the theory of the resistance of fluids.

CHAPTER V.

On the Suction of Bodies with tapering Stern-ends of the same Length, but differently curving.

THE theory of the motion of water is rather difficult to be understood, to comprehend how the action of the water, in closing on the tapering stern-ends of bodies in motion, is affected by the straightness or the fulness of the curve of the line of tapering stern-ends. That there should be (as has been shewn) any instances of a greater length of taper of stern-end occasioning a greater impediment to velocity than a shorter length, is remarkable.

The curving stern-end of the body of this *Figure* as well as the stern-end of this *Figure* occasions a greater impediment to velocity, than the body of this *Figure* and from the same cause which has been pointed out, the two former have the same length of stern-end; the one forming an equilateral triangle, being the same body as described by *Figure* A, in TABLE XIV., and the other, a segment of a circle of one foot radius. There is something peculiarly disadvantageous in this particular length of taper of stern-end; for the first of these bodies obtains less velocity with the same power, than this shorter curve stern-end of a segment of a circle of six inches radius; because the attracted water is not exposed to the tenacity and friction of the closing fluid. It is still further to be remarked, that this last described figure has less suction than this one, and for this reason; the suction is somewhat lessened by the stern-end being lengthened a little, and not being

lengthened so much as to fix the attracted water in a position to be drawn against, and in opposition to the closing fluid, as is the case with the two figures first described.

This precise length of taper of stern-end (an equilateral triangle,) is also equally disadvantageous to bodies when moving close below the surface of the water, as has been before observed. It demands particular precaution in designing vessels, that the length of the taper of the stern-end should always be greater than an angle of such proportion.

It has already been shewn, that (excepting in the particular case just alluded to), the suction is always more or less, according to the shortness or length of the taper of the stern-end of bodies. By reference to TABLE XV. it will be seen, that the suction of stern-ends of the same length of taper varies also, according to the roundness or straightness of the curve of the stern-ends.

The *Figures* in TABLE XV., describe three bodies having the same midship-part and bow-end, and the same length of stern-end; but one having a stern-end with a straight (water) line, another with a small curve, and the other with a very rounding or full curve stern-end; all three bodies are moved through the water at six feet depth. The *Figure* with a full curve stern-end, obtains the least velocity with the same weight or power at every rate of motion; the extremity of the stern-end being so obtuse, the closing fluid has not time to close with effect against the extremity of the stern-end; and a quantity of water is drawn after it, and in a direction to be drawn against, and in opposition to the closing fluid. The *Figure* with a small curve stern-end, obtains more velocity than the one with a straight line, in motions under $5\frac{1}{2}$ miles an hour; the water having sufficient time at these slow velocities to close against the extremity of the stern-end with the small curve; and the straight line makes a greater angle at the midship-section than the small curve, which occasions a partial obstruction from the deflection of the water. Above the velocity of $5\frac{1}{2}$ miles per hour, the straight line obtains the greatest velocity with the same weight or power; the water not having sufficient time to close with effect against the after-part of the stern with a small curve, when the body is moved at greater velacity.

TABLE XV.

EXHIBITING the difference in the velocity of bodies, with stern-ends of the same length but different capacity and form; arising from the difference in the suction, occasioned by the difference in the form only of the stern-ends. These bodies are moved through the water with equal weight or power, at the depth of six feet below the surface; and each of the three *Figures* have the same midship-part and bow-ends, and the same length of stern-end. The TABLE also shews the increase of velocity, from double, triple, and quadruple increase, of weight or powers.

Increase of weight.	Weight to give velocity.	*Small Curve.* Velocity, feet per second.	Increased rate of velocity.	Additional velocity, feet per second.	*Straight Line.* Velocity, feet per second.	Increased rate of velocity.	Additional velocity, feet per second.	*Full Curve.* Velocity, feet per second.	Increased rate of velocity.	Additional velocity, feet per second.
	lbs.	Ft. dec. pts.		Ft. dec. pts.	Ft. dec. pts.		Ft. dec. pts.	Ft. dec. pts.		Ft. dec. pts.
Double	12	3,90	1 37/100	1,44	3,88	1 37/100	1,44	3,80	1 37/100	1,42
	24	5,34			5,33			5,22		
	36	6,43	do.	2,37	6,41	do.	2,39	6,30	do.	2,36
	72	8,80			8,80			8,66		
	48	7,32	do.	2,71	7,31	do.	2,72	7,19	do.	2,70
	96	10,03			10,04			9,89		
	60	8,10	do.	3,00	8,10	do.	3,02	7,97	do.	2,99
	120	11,11			11,12			10,96		
Triple	12	3,90	1 64/100	2,52	3,88	1 63/100	2,53	3,80	1 65/100	2,50
	36	6,43			6,41			6,30		
	24	5,34	do.	3,46	5,33	do.	3,47	5,22	do.	3,43
	72	8,80			8,80			8,66		
Four times	12	3,90	1 87/100	3,42	3,88	1 88/100	3,43	3,80	1 89/100	3,39
	48	7,32			7,31			7,19		
	24	5,34	do.	4,69	5,33	do.	4,71	5,22	do.	4,66
	96	10,03			10,04			9,89		

It appears therefore, that this small swell or curve, or deviation from a straight line in the taper of the stern-end, retards the velocity of the body, only when moving at velocities above $5\frac{1}{2}$ miles an hour. And that the small curve at the stern-end, is an advantage to velocity in slow motions; although a disadvantage in quicker motions. The full curve is disadvantageous at every rate of velocity; since by the obtuseness of the extremity of the stern-end, a considerable degree of suction is always created.

The *difference* in the velocity arising from the difference of the suction between the body with a full curve stern-end, and that with a straight line, increases about double, with triple increase of velocity. That between the body with a full curve and small curve stern-end, increases but little with increase of velocity, about one third with triple increase of velocity. That between the body with a small curve stern-end and a straight line, cannot be brought in comparison; for at smaller velocities, the straight line has rather more suction than the small curve; and at greater velocities, the small curve has rather more suction than the straight line.

It will appear by reference to TABLE XV., that the *Figure* with a full curve stern-end, has more suction at every rate of velocity, than either the one with a straight line, or a small curve at the stern-end. And it appears further, that the *Figure* with a small curve stern-end, has the least suction when moved through the water at velocities under $5\frac{1}{2}$ miles per hour; and the figure with a straight line has the least suction, when moved at greater velocities through the water. The suction of the body with a small curve stern-end, when moving through the water at the rate of $6\frac{1}{2}$ miles per hour, is equal in weight or power to $\frac{1}{3}$ of a lb., when moving at the rate of $5\frac{1}{4}$ miles per hour and under, it has no suction. It is evident therefore, that a stern-end may be so formed as to create a suction at greater velocities, and at lesser velocity experience more whatever; the curve, therefore, should always be regulated suitably to the greatest velocity at which the body is intended to move through the water. The suction of the body with a full curve stern-end, when moving through the water at the rate of $2\frac{1}{4}$ miles per hour, is equal in weight or power to $\frac{3}{5}$ of a lb.; and when moving at the rate of $6\frac{1}{4}$ miles

per hour, to $3\frac{1}{2}$ lbs. weight. And it must be observed, that at whatever velocity the suction commences, it always increases with the velocity, in an increased proportion; and in a greater proportion, when a body has a stern-end formed with a full curve, than when with a small curve.

The *Figures* described in TABLE XV. are those described in TABLE X, only moved through the water with the opposite ends foremost. It is worthy of observation, that by a comparitive view of the velocities of the same bodies, moved the reverse way, it will appear, that the full curve, and also the small curve, is a greater impediment to velocity, when at the stern-end of bodies, than when at the bow-end; at every rate of motion specified. Thus it appears, that a too great fulness of curve at the bow-end, retards the velocity of a body less, than the same fulness of curve at the stern-end.

The bodies described by the foregoing *Figures*, were moved in the water at *six feet depth*: a few observations occurs in a comparative way, with bodies moved *close below the surface* of the water; *viz.* A body having a stern-end formed by a hollow line or curving inwards, obtains more velocity with the same power, than it would do, if the stern-end was formed by a curve, curving outwards. A body whose bow-end is formed with a hollow curve (or water-line,) and whose stern-end is round, will obtain less velocity with the same power, than it would do, if the round water-line was at the bow-end, and the hollow line at the stern-end. But supposing a body to have a water-line extending in a fair curve, from one end of it to the other, and the curve to be rather more rounding at one extremity than at the other, the body obtains the most velocity with equal power or weight, when moved with the straightest curve at the bow-end. And a body having a bow-end formed by a very long and acute angle, and a stern-end, formed by a very obtuse angle, obtains more velocity with the same power or weight, when moved in that direction, than when moved with the obtuse end foremost.

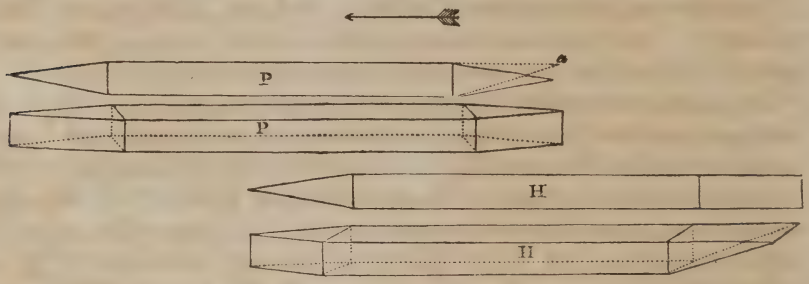
And again, a long round piece of timber, being 7 inches diameter at the smallest end, and 14 inches diameter at the largest end; and being drawn

along the surface of the water with a certain power or weight, will, with the same weight, go at the rate of 26 miles per hour, with the small end foremost, and only 18 miles an hour, with the large end foremost. These circumstances, however, only occur when bodies are moved close to the surface of the water; and it must be observed, that in trying experiments, there is a difficulty in keeping bodies steady and parallel with the surface of the water when moving close below it; and the results cannot be so much depended on, as when bodies are moved at greater depths.

CHAPTER VI

On the Suction of Stern-ends of the same Length, and the same Capacity, but of different Form.

THERE is, a difference in the suction of stern-ends of the same length, and of *precisely the same bulk* or *capacity*, owing to the difference of form.



The above sections of two *Figures*, P and H, describe bodies with stern-ends precisely of the same bulk or capacity, and of the same length; the midship-part and bow-end of each body are the same, and have each one foot area of surface of midship-section. But the water closes on the stern-end of P in a lateral direction against *each* side, and against that of H on *one* side only; *viz.* in an upward direction, below the under side.

The stern-end of P has no suction at the velocities specified. H has a suction at every rate of velocity; and the suction increases prodigiously with increase of velocity. When the body H is moving through the water at the rate of $1\frac{1}{4}$ miler per hour, the suction is equal in weight to $\frac{8}{100}$ of a lb.; and when moving at the rate of $6\frac{3}{4}$ miles per hour, the suction of H is equal in weight to $9\frac{1}{4}$ lbs. And it must be observed, if the stern-end of H had been

square (without the angle at the stern,) and in consequence of a form to create almost the greaest suction, in that case, the suction when moving at $6\frac{3}{4}$ miles per hour, would be equal to 17lbs. weight.

The great difference in the suction of these two bodies P and H, and both having stern-ends of the same bulk or capacity, and the same length, demands observation. It arises from the angle of the stern-end P, becoming more tapering, in consequence of its meeting in the middle, and from the water acting by its pressure and velocity to close on *each* side of the stern-end P. Whereas the angle of the stern-end of H meets at the upper side, and crosses the whole depth of the body, and becomes more obtuse in consequence; and the water closes against but *one* side only; *viz.* the under side.

This difference in the suction of the stern-ends of these two bodies, does not arise because of the water closing on that of H in an *upward* direction, since water closes in every direction with the same facility; and the same difference would occur in the suction, if the stern-end of P was formed according to the dotted line angle *a*, and the water in that case closing laterally against *one* side of the stern-end only; *viz.* against the angle formed across to the side; and in the other case, closing on both sides of the stern-end; *viz.* against the angle meeting in the middle.

The great importance, therefore, of giving the lines of the stern-end of vessels, as tapering a termination as the capacity will possibly admit, so as to be sufficiently tapering, is obvious; and thus this advantage, by the water pressing and acting on *each* side of the stern-end, in order to close after being displaced, instead of being enabled to close but on *one* side only, is by the foregoing made manifest.

The *Figures* before described, are the very same as those described in PART I. CHAPTER VIII., only moved through the water in an opposite direction, with the opposite ends forward. H obtains greater velocity when the slanting end is moved forwards, which shews, that the increase of the suction from such a stern-end, it a greater impediment to velocity, than that from the increase of the resistance from such a forward bow-end.

CHAPTER VII.

On the Suction, as it more intimately applies to the Form of the Bodies of Ships.

THE form of the stern-end o ships below the surface of the water, presents various positions to the closing water. In some parts, the water closes against the stern-end of a vessel, in a lateral direction, as against that of *Figure* P in the preceding Chapter; at other parts, in an upward direction, as against that of *Figure* H.; at other parts, in a direction between the two; *viz.* diagonally; and again, at other parts, the closing water is compelled to follow the stern-end, in its efforts to close against it. Therefore, the operations either to lessen or to do away the suction, vary in consequence thereof.

The extremity of the stern-end of vessels being fuller *toward the surface* of the water than at any other part, the suction becomes more considerable *there* than any where else; for the direction of the water in closing there, becomes at right angles with the line of motion, because of the water-line being terminated in that direction from the fulness of the stern-end. It is, therefore, hardly possible for the closing water even to come in contact with that part of the body when in motion, and particularly as the closing water moves slower toward the surface than at greater depths.

The water toward the surface is, therefore, obliged to close at some little distance beyond the stern; and, between the closing water and the stern, a body of dead water accumulates in consequence, and which is drawn after the vessel by the suction. And this occasions an additional pressure on the midship-body of the vessel, equal in weight to that of the bulk of the dead

water; and it occasions also an impediment to its velocity, equal to the increase of velocity, which the vessel would derive from a power to impel it forwards equal to the weight of the dead water.

The velocity of the water in closing at 2 feet depth, is 11 feet per second; and when vessels in general are moving through the water at 9 or 10 feet per second, one begins to perceive the broken and eddy water under their sterns, and to feel perceptibly the effects of the suction. This bulk of dead water is frequently so considerable, when vessels have very full stern-ends, as to extend behind the stern beyond the rudder; insomuch, that a large portion of the rudder being enveloped with the dead water, the rudder has not sufficient power to steer the vessel, particularly when tacking about in working to-windward. But, then, this body of dead water does not extend to any great depth (except when vessels are very full at the stern-end, and that the fulness is continued down some depth below the surface of the water), the velocity of the water in closing being rapid even at a small depth, and the stern-end of vessels generally beginning to taper at a little distance below the surface of the water. What appears like broken water at a more considerable depth, is nothing more than the concussion of the closing particles from each side of the vessel—one body dashing against the other. This dead water is very visible; and nothing is more common than to see particles of rubbish floating on its surface, close under the stern of the vessel, accompanying her in her course for a long time.

Besides this dead water, it commonly happens that there is a depression of the water, upon its surface, at the rudder, or at a little distance beyond it—the water at the quarters of the vessel being higher than at midway between them, forms a valley; for the water closing from each side in a lateral direction, is restored last to its former level at where it meets; and, last of all, at the midway at the surface to restore itself to a level. And the velocity of water in closing near the surface is so very slow, that it takes some time to form a level; so that at a little distance beyond the dead water it is usually depressed, and it leaves an impression along the surface of the water which may be observed for a considerable distance after the vessel—commonly called by seamen the wake.

The lower part of the stern-end of vessels is always more tapering than any other part, and presents a perpendicular surface to the water; and it closes against it in a lateral direction, in a similar way as against the stern-end of the body P, described in the preceding Chapter. And the suction becomes more or less according to the fulness or straightness of the taper, according to the length of the taper, and according to the velocity of the vessel through the water.

From the form in which vessels are usually constructed, it is hardly possible to conceive there can be dead water at the lower parts of their stern-ends, considering the velocity of the closing water, and the length of taper at that depth—it there commencing from the midship-part.

The specific gravity of water to air, is as 1 to 800; and a cubic foot of fresh water weighs 1000 ounces, or about 62½ lbs. avoirdupois. The power of the air's pressure on all bodies near the surface of the sea, is computed to be about 14lbs. on a square inch, or 2016 lbs. on a square foot; and the weight of the pressure of air is equal to the weight of a column of water about 33 feet high.

The pressure of water at any particular depth, against a close hollow body containing atmospheric air, is equal to the weight of the water above it. Its pressure on a square foot at one foot depth, is 62½ lbs.; at five feet depth, 312 lbs.; at 10 feet depth, 625 lbs.; at 20 feet depth, 1250 lbs.; and at 33 feet depth, about 2016 lbs. Its pressure, therefore, is ten times greater at 10 feet depth than at 1 foot depth, and in that proportion at greater depths; and, owing to its fluidity, it presses equally in all directions, upward, downward, or sideways; so that the lateral pressure is equal to its perpendicular pressure at the same depth.

The pressure against a square foot of a hollow body containing atmospheric air, when immersed 33 feet deep, is 2016 lbs; but supposing the air were drawn out of the hollow body and a vacuum formed, there would then be not only the pressure of the water against it, but also the pressure of the atmosphere, in consequence of there being no air in it; and as the pressure

of the atmosphere is equal to the pressure of water at 33 feet depth, it follows that, when the body is immersed at that depth, there must be double the pressure against it as when it contained air. And the pressure of the atmosphere on a square foot of surface being 2016 lbs. and the pressure of the water at 33 feet depth being also 2016 lbs., the whole pressure at that depth becomes double, or equal to 4032 lbs.

The pressure, therefore, against a vacuum, below the surface of the water, is equal to the weight of the atmosphere, and to the weight of the water above the vacuum added to it. The pressure of the atmosphere only, is at the very surface. At one foot below the surface, a vacuum being formed, the pressure in that case would be equal to the pressure of the atmosphere 2016 lbs., and to the weight of 1 foot of water $62\frac{1}{2}$ lbs.; *viz.* 2078 lbs., at five feet depth, to 2016 lbs., and 312 lbs. added; at ten feet depth, to 2016 lbs., and 625 lbs. added; and at twenty feet depth, to 2016 lbs., and 1250 lbs. added together.

The whole pressure, therefore, exerted to fill up a void at 33 feet depth in water, is double what it is close below the surface; and at $16\frac{1}{2}$ feet depth in water, to three quarters as much as at 33 feet depth: and in equal proportions between those depths. And the pressure increases in like manner at greater depths; at 66 feet deep, it is three times greater on a vacuum than it is close below the surface of the water.

Now, in consequence of the *weight* of water, it obtains a greater velocity in filling up a void, or vacated space, at greater depths than at lesser depths: and, owing to its fluidity, it obtains the same velocity at any particular depth, as that which a heavy body would obtain by an accelerated motion, in falling from a height equal to such depth.

All bodies, whatever be their weights, descend near the earth's surface, through equal spaces, in equal times, abstracting the resistance of the air; for the resistance of the air to falling bodies is evinced by exhausting a tall glass receiver of its air: and in that state the lightest body, as a feather, will fall in it as fast as lead.

Thus, bodies falling in a perpendicular direction, obtain an accelerated motion in this proportion, admitting a heavy body to fall 16 feet in a second; *viz.*

Time.	Whole distance fallen.	Distance fallen each moment.	Rate of acceleration is	Momentary increase of distance is the *number* multipled by 16.	Increase.
Moment.	Feet.	Feet.	as		
1	16	16	1	----------	16
2	64	48	16)48|3	2 is the square root of the number 4, 4 times 16 is	64
3	144	80	16)80|5	3 is the square root of the number 9, 9 times 16 is	144
4	256	112	16)112|7	4 is the square root of the number 16, 16 times 16 is	256

Thus water falls in the air 1 foot in a $\frac{1}{4}$ of a second, 4 feet in $\frac{1}{2}$ a second, 16 feet in 1 second, 64 feet in 2 seconds, &c. &c. And the velocity of water running out of the bottom of a container, arising from the pressure of its weight, is the same as that which a heavy body would acquire, in falling from a height equal to the depth of the container.

And thus the velocity of a spouting fluid is found to be that of falling from the height, from the surface of the fluid. And the quantity of water, running out of a hole in the bottom of a container, is equal to a column of water whose base is the area of the hole, and its altitude described in that time by the velocity acquired by a heavy ball falling through the height of the fluid.

The momentum, or force of bodies, depends on their weight: the force of a body weighing 10 lbs., and moving with a velocity of 3 miles per hour, is equal to that of a body of 5 lbs. weight, moving at a velocity of 6 miles per hour. (10 times 3 are 30 and 5 times 6 are 30.)

The air is of an elastic, springy nature; and the force of its spring is equal to its weight. The whole atmospheric force, to rush into a void, close below the surface of the water, is equal to 2016 lbs. weight, on a superficial foot; and the air rushes into a void with a velocity of 1340 feet in a second; if therefore a cannon-ball moves with greater velocity through the air than 1340 feet in a second, it sustains the whole pressure of the atmosphere against its fore-part, besides the resistance from the inertia of the particles of the air, for it leaves a void behind; hence men are so frequently knocked down by the wind of a shot, or by the rush of the air to fill up the vacuum. And all bodies moving in a medium are operated upon, more or less, according to the rarity or density of the medium, and according to the velocity of the body. The planets, in their course, may feel some effect from this upon the fluid part of their surface, and which may, possibly, in some measure, operate on the tides.

The velocity of quicksilver, 30 inches high; of water, 33 feet high; and air 5 miles high (being all of them the same weight); estimating the pressure by the whole altitude, and the air rushing into a vacuum, is; viz. quicksilver, 30 inches high, velocity 12 feet per second; water, 33 feet high, 47 feet per second; and air, 5 miles high, 1340 feet per second.

The velocity of water, in closing against the tapering part of the stern-end of ships, depends on the depth at which the water closes; and this velocity may always be ascertained by multiplying the depth by $64\frac{1}{7}$; and the square root of the product is the velocity: and the water moves with the same velocity, in every direction, at the same depth, in filling a vacated space, excepting any circumstances tend to retard its velocity, as happens when ships are sailing fast, and come into shoal water; the water, meeting with an obstruction in its closure, from passing over the ground, cannot act with its natural force; there is then a perceptible agitation and difference in the motion and appearance of the water, round the stern of vessels, and in its effect on the rudder; on perceiving this, the sailors have a saying, that the vessel smells the ground.

The suction at the lower part of the stern of vessels, is either lessened or

entirely done away, by the action of the closing fluid; and this has a velocity equal to the accelerated velocity of a heavy body falling from a height, equal to the depth of the lower part of the stern-end, from the surface of the water, and the water moves in every direction with the same velocity in closing on the stern; it has an equal motion sideways, and both to follow the vessel, and to pass the vessel; it has, however, no other tendency to pass the vessel, than what it acquires by its own velocity in closing; for it is the vessel which has the motion through the water. The force of the closing water, in the direction to follow the vessel, must lose much of its effect, in consequence of the motion of the vessel from it; whereas its force in the direction to pass the vessel, must have a considerable increased effect, by the motion of the vessel toward it. The effort of the closing fluid must therefore be in a direction between the line of motion, and at right angles from it, in a diagonal direction, in a similar direction to that of the taper of the stern-end or after-body.

When the taper of the stern-end is of a sufficient length, the closing water acts with so much force against it as to remove the attracted water; and further, the closing water impinges and moves with such power, as to cause a pressure against the tapering stern-end, equal to the pressure it has when at rest. When the taper of the stern-end is not of a sufficient length, the closing water cannot exert its full power; a body of water is then attracted after the vessel, against which the closing water comes in contact, and moves it, so that it accompanies the vessel with only a part of its velocity; the closing water also diminishes the quantity of the attracted water, and lessening the effect of the attraction, the suction is therefore diminished; but then it is only diminished, and not done away. And when the taper of the stern is of a sufficient length, if it is of a curving form, and so full as to prevent the closing water exerting its full power against every part, a suction will still arise at those parts where it cannot exert its full effect, and which is toward the termination of the curve, at the extremity of the stern-end: a small curve, or deviation from a straight line, will occasion a suction, and a considerable impediment to the velocity of the vessel; and the greater the velocity of the vessel, the more the obstruction increases.

The velocity of the water, in closing, is always the same, let the velocity of

the vessel be what it may. The greater the velocity of the vessel, the longer the taper of the stern-end is required to be; for the water may have sufficient time to exert its full power against a longer taper, and not sufficient time to do so against a shorter taper. Again, the slower the motion of the vessel through the water, the shorter the taper of the stern-end, or after-body, need to be; for the water may have sufficient time to exert its full effect on a tapering stern-end, when a vessel is moving at a certain velocity, and not a sufficient time when moving at a greater velocity.

The velocity of the water in closing, varies at every depth, increasing in velocity with its depth, according to the accelerated velocity of falling bodies; the velocity of water at a *small* depth, may be insufficient to close against a stern-end of a certain length, while that *below*, may be fully sufficient; therefore, those parts of the tapering stern-end, or after-body, which are immersed the deepest in the water, require less length of taper, than those above them.

To shew more clearly the effect of the closing water, at different depths, on the tapering stern-end: Supposing a body, 30 feet wide and 20 feet deep, floating on the water, having 15 feet of its depth immersed; that the midship-section was square, or with upright sides and flat bottom, the bow-end sharp; and supposing it had a stern-end, 50 feet in length from the midship-section, regularly tapering to a point at the stern, similar to a wedge with its edge upright, only that it had a longer taper at the surface of the water than at the lower part of the body. When this body is moved through the water, at any velocity whatever, the velocity of the water, in closing on its stern-end, is always the same. The velocity of the water is moreover always the same at the *same* depth, but it is greater at greater depths than at lesser depths; of course, let the velocity of the body be what it may, there must be a certain and invariable form, which the water assumes in its closure, and the nearer this stern-end is made to correspond with this form, and then the nearer it presents a position also, that the closing water may act against it with the greatest effect, the less must be the suction.

Now, as the water closes slower near the surface, than at greater depths, it will clearly appear that this stern-end requires a longer termina-

tion or taper, at the surface of the water than at the lower part. The body being 30 feet wide, and the stern-end close below the surface of the water, 50 feet long, the water has to close 15 feet against each side of the stern-end, while the body is moving 50 feet through the water. The velocity of water in closing at 1 foot depth, is 8 feet per second; therefore, when the body moves at a velocity of 26 feet per second, the water by its own velocity will close 15 feet, in the time the body moves forward 50 feet.—Therefore, supposing this body to be moving through the water, at a velocity of 26 feet per second, the water will just have time to close against the taper of 50 feet long, at 1 foot below the surface of the water. The velocity of water in closing at 7 feet depth, is 21 feet per second, and the velocity of the body being 26 feet per second, if the water will close 21 feet while the body moves forward 26 feet, it will close 15 feet while the body moves 18 feet, and therefore the length of the taper of the stern-end, at 7 feet depth, requires to be only 18 feet, whereas at 1 foot below the surface, it requires to be 50 feet in length, in order that the water may have time to close against it, when the body moves at the velocity of 26 feet per second. The velocity of water in closing at 15 feet depth, is 31 feet per second, and the velocity of the body being 26 feet per second, if the water would close 31 feet, while the body moves forward 26 feet, it will close 15 feet while the body moves $12\frac{1}{2}$ feet, and therefore the length of the taper at the stern-end, at 15 feet depth, requires to be only $12\frac{1}{2}$ feet; whereas at 7 feet depth, it requires to be 18 feet long; and at one foot below the surface it requires to be 50 feet long, in order that the water may close against it, when the body moves at the velocity of 26 feet per second, or about 15 miles per hour.

Supposing, therefore, the stern-end of this body to have a taper of 50 feet in length, from the midship-section, at 1 foot below the surface of the water; of 18 feet in length, from the midship-section, at 7 feet depth; and of $12\frac{1}{2}$ feet in length, from the midship-section, at 15 feet depth; and that the water closed against every part, when the body is moved forward at the velocity of 26 feet per second:—The water, in this case, has a sufficient time, and only so, just to close on the stern-end; it cannot act with any power, either in lessening the attraction of the water by the suction, or in lessening the quantity of the attracted water; nor can it act with any force or pressure against

the stern-end; the suction would not, therefore, be in the least diminished; the taper of the stern-end would require to be made considerably longer at the different depths, before it could present a surface in a direction for the closing water to exert its full power against it.

As the velocity of the water, and therefore the time the water takes in closing, never varies, the proper length of the taper of the stern-end depends upon the velocity of the body through the water, since the closing water might have sufficient time to act with its full force, when the body is moving at a certain velocity; and not sufficient time when the body is moving at a greater velocity. If, for instance, this body was impelled at the velocity of 52 feet, instead of 26 feet per second, the water would have only one-half sufficient time to close against the stern-end; and if the body was moved at the rate of 13 feet instead of 26 feet per second, the water would have double the time than is necessary to close against the stern-end. And in like manner, the proper length of the taper, in order that the closing water may act against it with its *full* effect, requires to be regulated according to the velocity of the body through the water; and it must always be considerably *longer* than merely to let the water close against it.

The lower part of the stern-end, or after-bodies of ships, have, in consequence of the suction, a tendency to attract a quantity of water after them, which is lessened, more or less, by the force of the closing water, according to the length of the taper, and to the velocity at which they move through the water; and the suction is always greater with a short taper than a long one, and increases with the velocity; but the suction increases less in proportion with increase of velocity, with a long taper than a shorter one. The more the tapering line inclines from the line of motion, the less power the closing water has to remove the attracted water; and the more the tapering line becomes parallel with the line of motion, the greater is the power of the closing fluid on the attracted water; and the greater the velocity of the vessel, the less is the power and effect of the closing water.

The taper must be of very considerable length before the suction can be even at all lessened; the angle represented by the middle line of a ship, from mid-

ships to the stern-post, and by the water-line, from the stern-post along the bottom forward, must be less than 31 degrees, before the suction will be at all diminished: when the taper is at this angle, the attracted water accompanies the vessel, and is dragged against the closing fluid, and there is not only the full power of the suction, but also the friction of the dead water against the closing fluid; and it has been proved by experiment, that a taper of this angle (the equilateral triangle) causes a greater impediment to velocity than if there was no taper whatever; and there must be a considerable greater length of taper than this, before the closing water can act against it with its greatest effect, and this length must be increased according to the velocity of the body; for a greater length of taper would escape suction, when a vessel sails at the rate of 12 miles an hour, and a shorter taper would be subject to it; and again, this shorter taper would escape suction at slower velocity.

When the taper is of such a length that the closing water acts upon the attracted water, with only a partial effect, it moves it and lessens its motion with the vessel; the attracted water follows the vessel then with less velocity than the vessel sails at, and the quicker the water follows the vessel the greater is the suction. The attraction of the dead water is always at right angles with the stern-end, and the effect of the closing water in removing it is in the direction of the taper of the stern-end.

When the taper is made of such a length that the closing water removes the attracted water, still a force is required from the closing water against the tapering stern-end equal to the pressure it has when at rest, before the suction can be entirely done away. Thus, when the taper is made of such a length for the closing water to act against it with its full effect, the attracted water is entirely removed; and the closing water, by its impinging force against the taper, exerts the needful pressure, and the power of this pressure is in a perpendicular direction with the taper, and its tendency, to impel the vessel forward similar to the force of the wind on the sails of a vessel, when placed in an oblique direction. And when a ship is sailing at her greatest rate of velocity, the angle which the taper of the stern-end should make with the direction of the closing fluid at that time, should be similar to

that of the angle of the sails of a ship with the direction of the wind, when placed in the most advantageous position, to impel the vessel forward in oblique courses; the taper of the stern-end should not, however, be longer than to form such an angle, for, if longer, the water will not act with the strongest effect.

Having, therefore, shewn in what manner the suction on the lower part of the stern-end of vessels is done away, by the efforts of the closing water, acting in a lateral direction, against the *perpendicular* surface of its taper, it will be needful to shew the operation of the suction, and the means to counteract its effect on that part of the stern-end of vessels which is higher up, and which rests *flatly* upon the water.

The stern-end, or after-body of vessels, rises or slants gradually upwards, from the flat of the floor at the midship section, to the wing transom at the extremity of the stern, just above water, and in the direction across the vessel, it rests flatly on the water. In consequence of the after-body slanting upward, from the lower part of the midship-section to the extremity of the stern, at the surface of the water, in an oblique direction, between a level and a perpendicular, but much nearer to that of a level; the after-body has a tendency to forsake the water, when the vessel is in motion, and to dip from the loss of its support.

The support which every floating body receives from the water is directly upward; it receives but little support sideways, or in any other than in a vertical direction; this can be made evident; for if a floating body in the shape of a box, with a flat bottom and upright sides, be put in a reservoir of water, and brought with one of its sides to the side of the reservoir, and the side of the body come so close to that of the reservoir as scarcely for any water to be between them, the body would not lose the least of its support from the water, nor would it rest with the least weight or pressure against the reservoir; but it derives its support, almost entirely, from the efforts of the water upwards, under the bottom.

When a vessel is moving through the water, that part of the after-body which rests on the water, in an oblique direction, tending upward from the flat of the floor in midships toward the stern, at the surface of the water, has a tendency to lose its support, in consequence of the vessel moving in a level

direction, and the line of support of the after-body, being in an oblique direction; and as the upper part of the after-body of the vessel is above water, and subject to the whole pressure of the atmosphere, the atmosphere has as much power in preventing any vacuum being formed, under this part of the after-body, as it would have in its operation on the midship-section to cause it, if the body was wholly immersed. The after-body, therefore, on losing any of its support from the motion of the vessel, dips down, by the pressure of the atmosphere, as well as by its own weight. But if the vessel is firmly put together, and inflexible, the after-part could not subside without the midship-section being deeper immersed; for the stern-end, on losing any of its support, would bear down the midship-section; and by the midship-section being deeper immersed, there would be a greater area of resistance, and this increase of resistance must be equal to the suction which would arise, from the tendency to vacuum, between the under-part of the after-body and the water, when the vessel is in motion; if, the pressure of the atmosphere on the upper part of the after-body above water, and the weight of the after-body did not prevent it, by its subsiding in close contact with the water.

Now if the vessel was pliable, and would bend in midships, so as to yield to this subsidence of the after-body, without depressing the midship-section, she would then escape the additional resistance which would otherwise occur.

Supposing, for instance, the after-body were required to subside 3 inches, in consequence of the loss of its support, from the motion of the vessel: now if the vessel was so firmly built as to be inflexible, the after-body could not subside 3 inches, without the midship-section also subsiding, and there would be an increase of area of resistance of midship-section; but if the vessel was pliable, and yielded in midships, and suffered the stern-end at its extremity to drop 6 inches, it would meet with the necessary support, without depressing the midship-section at all, and thus relieve itself from the additional impediment to its velocity.

This subsidence, or sinking down of the after-body, operates on such parts of the after-body, as rest flatly on the water; but the lower parts of the after-

body can receive no relief from such subsidence; for its surface being there in a perpendicular direction, and the subsidence being also in a perpendicular direction, it can have no possible effect; whereas those parts of the after-body, which rest flatways on the water, subside upon it in a perpendicular direction.

The advantage of the stern-end of a vessel, being formed as much as possible to obtain relief from subsidence, is obvious; that is, in case the vessel is pliable, and the great importance of their being so formed, and of the pliability of construction, must be manifest: for if the vessel is inflexible, the power of the wind on the sails, to elevate the stern-end, acts on the equilibrium of the two extremities upon the centre of gravity, and which is easily operated upon, the two extremities being on a balance, and the more the stern-end is elevated, the more the midship-section and fore-body is depressed, and the resistance is oftentimes prodigiously increased; but if the vessel is pliable, then the whole weight of the after-body acts in opposition to the force of the wind on the sails to elevate it, and thus the subsidence is not lessened, and, of course there will be no depression of the midship-section and fore-body.

A ship which is pliable obtains great advantage, when the weight of ballast, or what she contains, is so deposited that the displacement of the water under the extremities of the vessel, is greater than their specific weight requires for their support; or, as if the two extremities suspended or supported a weight in the midships; for, in consequence of the pliability of the vessel, the fore and after-bodies would be forced up a little, by reason of the buoyancy of the water under them being greater than their specific weight requires; and thus an elastic, or a lively portion of pliability would be obtained.

Every thing which has a tendency to prevent or lessen the subsidence of the after-body, impedes the velocity of the vessel: hence arises the causes of trifling and curious circumstances affecting the sailing of a ship, and which have appeared so unaccountable; such as the suspending a weight on the middle of the main-stay, and not letting the stay be too tight; slacking

the back-stays, letting the shrouds be a little slack, and raking or inclining the masts more or less from a perpendicular, &c. Now by raking the masts aft, and letting the main, fore, and mizen-stays be a little slack, with a weight suspended on them, the *weight* of the masts, sails, and rigging overhanging a little aft, and not being confined, give an elastic force against the wind, and counteract, in some measure, the lifting of the stern by the pressure of the wind on the sails; as also does the slacking the back-stays, and keeping the shrouds a little slack.

Frequently it has been found, that the putting a stopper on the main stay, and confining it down to the deck, has materially injured a vessel's sailing; and the reason is, because it prevents the mast from having that elasticity, or play aft, against the pressure of the wind on the sails: thus also the setting the shrouds up too tight, and keeping the back-stays tight, confine the masts, and cause a full and instantaneous effect of the wind on the sails to lift the stern. Trifling circumstances, such as bringing a few of the foremast guns toward the midships, have been known to make a difference in a vessel's sailing; and this is, because of easing a weight so far distant from the centre of gravity, and having therefore so much greater power, in confining the elastic pliability of the vessel.

It has been often found by experience, that two ships, which have been built upon the same plan, and apparently exactly alike in all respects, that one of them has sailed well, and the other very badly; and if it has not arisen from the difference in the pliability of their construction, it is because some of the circumstances just alluded to, or other similar ones, have happened accidentally in one ship, and not in the other.

Many other circumstances could be mentioned, to have excited the observation of seamen, which have appeared of a trifling nature, and yet caused a great difference in the sailing of vessels; but the cause of their powerful operation is evident. If such circumstances were judiciously attended to, the sailing of most ships would be greatly improved. But because these circumstances have appeared so unaccountable, and their effect not rightly understood, mariners have applied their efforts to experiments in finding out

the *trim* of ships; and being seldom guided by judgment, their success has usually been uncertain, a matter of chance, or of discovery merely accidental.

Instances have been known, when vessels have been pursued by an enemy, and when extraordinary efforts in sailing have been required, that the sides of vessels have been cut down (sawn through) in midships, whereby their sailing has been so much quickened as to have effected their escape. The reason is, the vessels have thereby obtained more pliability: a more effectual means of enabling the after-body to subside could not have been resorted to. Experience and observation has induced a common opinion, that pliability in the construction, enables ships to sail faster; but how it has operated to do so, has not been rightly understood; nor has it been attended to in their construction, as its importance demands; there is certainly a difficulty in combining strength with pliability; there is, however, no question but it may be done. It is presumed the diagonal system now adopting in building ships of war, increases strength, but not pliability.

When a vessel is sailing near the wind, (in an oblique direction with the wind,) the bow is not depressed, nor the stern elevated, as is commonly the case when vessels are going before the wind; the suction consequently becomes less, when a vessel is sailing near the wind than when going before the wind, inasmuch as the wind has no power to lessen the subsidence of the stern-end (or after-body). And in consequence of the lee-way of the vessel, the wind forces the lee side of the after-body against the closing water, and thereby increases its power on that side; on the other hand, forces the windward side of the after-body from the closing water, and thereby lessens its power on that side; the suction would therefore be greater on the *windward* side of the after-body (that side the wind blows against), than on the lee side of the after-body (the side from the wind), provided the fulness of the extremity of the stern, at the surface of the water, was not immersed deeper on the lee side, and raised higher out of the water on the windward side, from the inclination of the vessel under the pressure of the wind on her sails.

The longer the slant can be made from the lower side or flat of the floor at the midship-section, to the termination of the stern at the surface of the water, the more the slant will be toward a level; and, in consequence of that, will have a less tendency to forsake the water when the vessel is in motion, and a less subsidence will be required in order to do away the effect of this part of the suction. And as the water closes on the after-body in every direction, any fulness or irregularity, in the lines which delineate its form in any direction, will occasion an impediment to velocity. It becomes needful, therefore, to pay attention to the length of termination, and to the curve of the lines of the after-body, in every direction; in the diagonal direction against the slant upwards, as well as in the level direction against the taper of the lower part of the after-body.

In order to ascertain the length of slant and of taper of the different lines of the after-body of a ship:—The natural direction which the form of the body presents, for the closing fluid to take against the after-body from commencing its closure at the midship part, must be considered; for the power of the closing water always acts at right angles with the surface of the after-body; and the lines to regulate the slant and taper, should take the same direction as the closing water would naturally take. —The time also must be calculated which the water, by its own velocity, will naturally take to close against those lines at the various different depths; observing that water closes quickest at greater depths, and slowest towards the surface, and that its velocity depends on the weight of water above any particular depth.—The greatest rate of velocity at which the ship is expected to sail, must then be considered; and these lines of the lower part of the after-body should be so regulated in their curve, and length of taper, that the water may have sufficient time to close against every part with its *utmost* force, when the ship is going at its *greatest rate* of velocity.

And the curves of the diagonal lines should be made rather fuller at greater depths, and straighter as they approach the surface, according as the velocity of the water facilitates its closure at the different depths: and the fullness should be so regulated that the water may close against every part with-

out meeting with any obstruction. The diagonal lines should have such a length of termination, or the slant be so graduated, that the water may close with facility; and at length restore itself to a level and fly clear off, when the ship is sailing at her greatest velocity.

As a vessel requires a sufficient breadth toward the extremity of the stern to support and lift it in high seas, and especially to prevent the waves breaking over it when going before the wind in heavy gales; and, further, as a vessel also requires a considerable breadth toward the stern, to give her stiffness under the pressure of her sails (or to prevent her from inclining too much), it is clear that a level line could not be formed sufficiently tapering toward the surface of the water, to enable the water to close on the stern in that direction; and that the after-body must necessarily diminish in a slanting direction, from the lower part of the midship-section to the surface of the water at the stern, in order to enable the water to close. The diagonal lines are therefore the proper ones to be delineated, being the direction which the water will naturally take in closing and restoring itself to a level; and they should have the longest possible termination. As the water closes quicker below and slower toward the surface, the diagonal lines should round from the midship-section; and, as they approach nearer the surface, become quite straight, and then a little hollow close below the surface of the water at the extremity of the stern. This form of diagonal line would more intimately correspond with the natural form of the closing water against the after-body in its closure, than any other form of line whatever. And, moreover, a sufficient fulness can be made at the extremity of the stern, at the surface of the water, with but little impediment to velocity.

The exact form of these lines being ascertained by calculation, care should then be taken that there are no sudden curves in any direction whatever, but that all be perfectly fair and easy. Any unfairness in the lines create an obstruction to the closing water, and an impediment to velocity.

The form of the upper water-line (that is the line formed by the surface of

the water when the ship is at sea) requires particular attention; it should present a long line of bearing, or have a long continuation of breadth from the midship-part toward the bow and stern, in order to give stiffness, and afford support to the vessel under the pressure of the wind on her sails. But, then, this continuation of breadth should not extend below the surface of the water. The body below the surface of the water should commence its taper from the midship-section, both toward the bow and the stern, as soon as the lines will possibly allow of its being done with fairness.

Above the upper water-line, there should be a still greater fulness in this continuation of breadth toward the bow and stern, particularly toward the latter, which will be of much importance and advantage in supporting the vessel under the pressure of the wind on her sails; will make her very stiff or upright under canvass; and in consequence cause her to make less lee-way, and will be but of little impediment to her velocity. The body should spread or project out from that height where the water forsakes the vessel on the weather-side, when she is inclined by the force of the wind on her sails, and continue increasing in breadth as high as the water comes up to on the lee-side when she is so inclined.

It has been observed, that the water takes a much longer time to close near the surface than at greater depths: the greatest length of a vessel at the stern-end should therefore be at the surface of the water. The stern-post may be made to rake a little, or incline towards the midship-section below the water; the upper part of the stern should not project beyond that part at the surface of the water, if it could possibly be avoided; and as much as circumstances will admit, it would be of important advantage to the sailing of vessels, to have a termination of body at the upper water-line, extending even beyond the upper part of the stern; something similar to the representation of an old British ship of war, exhibited in the tapestry hangings of the House of Lords. In this respect, the form of our ships are now directly the reverse of what they ought to be, in order to obtain velocity. The sterns are made much longer above water than at the surface, and the lines are

made more tapering and straight below the surface than nearer to it, although the water closes quicker below and so very gradually at the surface. And this fullness of the after-body, in a diagonal direction, close under the upper water-line, creates a prodigious suction when ships are impelled rapidly through the water, and is a principal reason why our ships do not obtain a much greater velocity than the rate at which they now usually sail: and beyond which none of them can attain, because the suction at the stern, close below the surface of the water, becomes so great, in consequence of its fulness there, at the time when the ship attains her greatest rate of velocity.

There should be as great a length of after-body at the surface of the water as possible. In this respect we do not appear to have improved on our ancestors; to judge from the representation before alluded to. If a ship had its greatest length forward and aft, at the surface of the water, she would pitch less, be more weatherly, sail better, steer better, and strain less in a heavy sea.

When a ship is sailing, and the bow lifted by a wave, the stern becomes depressed, and any fulness abaft the midship-section becomes at such times a greater impediment to velocity. Care is required in a particular degree when delineating the after-bodies of vessels, that no part of the body abaft the midship-section should, at the time when the stern is so depressed, present any resistance to the water, after it has passed the midship-part; otherwise, when the bow is so elevated, the area of resistance will become enlarged by any fullness which presents itself abaft the midship-section. The diagonal lines under the flat of the bottom, and near the keel especially, should take a sufficient turn to diminish from the midship-section, so as to prevent the body close abaft it from presenting any resistance when the stern is depressed.

There should, moreover, always be an uniformity of proportion between the fulness or bulk of the bow, and the stern-ends of vessels. A vessel with a sharp fore-body, and a sharp after-body, will not pitch in a sea so violently (particularly in carrying sail upon a wind), as a ship with a full fore-body and

sharp after-body; because the bow and the stern of the one is more equal in bulk than the other; for the latter, having a full bow, will rise quickly at the wave; and, having less to support her at the stern, the stern will dip the more, and the bow rise so high in consequence that, at the next pitch, the vessel will plunge her bow with more violence than she would do, if the fore and after-body were of proportional capacity. A ship with a sharp fore-body and sharp after-body, will lay-to in safety; but a ship with a full fore-body and sharp after-body, will be a bad sea-boat when lying-to, and very wet and uncomfortable in carrying sail; will be liable to ship a sea on the quarter; and, when sailing near the wind, it will be needful to take in after-sail to ease her pitching.

But although a proportionable uniformity of fore and after-body is so essential to ease a vessel's pitching at sea, much also depends on the ballast and principal weight in a ship, being stowed properly; *viz.* toward the midship-part. As far as circumstances will possibly permit, this should be particularly observed, that no weight should ever be placed *at*, or even near, the extremities of a ship. By observing this, a vessel will be light and buoyant at the extremities, lively and easy in a sea, and her pitching-motion be thereby materially lessened.

A proportional uniformity in the capacity of the fore and after-bodies of ships being indispensable, their form and proportions, for this as well as for many other reasons, must necessarily differ from those of the fastest swimming fish. It must be allowed, that the formation of the bodies of fishes is truly excellent; and although theory does not coincide, yet experiments tend to confirm the fact.

It has been shewn, that, by experiment, a body with a full curve bow-end obtains a very rapid velocity with the same impelling power, as it would do if it had an acute bow. It has also been shewn, that the greater the velocity of a body, the longer the taper of the stern-end is required to be in order to avoid suction.

And thus, the fastest swimming fish has a short full entrance; and its ex-

treme breadth being near its head, it obtains thereby a very great length of taper of body to the tail. These fishes swim with that rapidity, that they will pass a ship under full sail (comparatively), as though she was at an anchor. Such a form is not, however, so suitable to other fishes that move with less velocity; they have a sharper entrance, and the extreme breadth further from the head, and less length of taper to the tail. And Nature most wisely varies the form and proportion of every fish, so as to pass through the fluid with the greatest ease to itself, at the velocity at which each particular fish requires to move in order to obtain its food, and for other necessary purposes.

PART III.

CHAPTER I.

On the Friction of Water on Bodies when moving in that Fluid.

IN addition to the impediments which ships meet with in passing through water, from the direct resistance thereof, and from the suction, there is yet another arising from the friction of the water against their bottoms.

That the friction of water is very considerable, is evident from the obstruction caused thereby, in passing through pipes; for a smooth pipe, $4\frac{1}{2}$ inches diameter, and 500 yards long, is found to yield but one-fifth of the quantity of water which it ought to do, independent of the friction.

The scales of fish are admirably placed in a direction to avoid friction, and an oily humour exudes from their bodies between the scales, by which the water is in a measure repelled, and they dart through it with but little friction.

Thus, if a ball of light wood is dipped in oil and put in a pan of water, the water will be repelled from the wood, and form a channel round it. And so great is this repelling power that, in some instances, bodies, specifically heavier than water, will, if perfectly dry, even float thereon. Thus, we see, that an iron needle, when it is dry, will swim on water. And water repels most bodies till they are wet; the particles attracting themselves to each other. Thus, drops of water may be observed to roll on the leaves of many vegetables.

Fish, therefore, in a measure, repel, or the water shrinks from them; and, by means of their air-bladders, and the elasticity of their scales, and bodily exertions, they contract, and dilate, and vary the position of the different parts of their bodies, as they find it needful, to lessen any partial obstruction to their velocity through the water. But it is beyond the power of human art so to construct ships as to effect these wonderful operations, and equally vain to attempt acquiring in them that rapid velocity which is natural to fish. Art, in every thing, possesses the same disparity—Nature is perfection—We are lost in admiration, and left only to presume an imperfect imitation.

The particles of water, although infinitely small, are, notwithstanding, disunited, somewhat similar to small shots when heaped up together, whose surfaces touch each other but at few places; for each particle of water being globular, the globules cannot unite—two round surfaces will not join. There is, however, some degree of cohesion in the particles, as if one shot is piled upon three others placed close together, there will be a hollow receptacle for it to go in to: and the shot being round, there will be a degree of fitness in the parts; so it is with the particles of water; but as they are perfectly smooth as well as globular, they are moved against each other with facility. There is no such cohesion, or fitness of parts, as to cause the least adhesion of one particle to another; it is the power of attraction which water naturally possesses and its power of gravity, which causes the particles to keep together.

There can be no fixed adhesion of the particles of water, except when they are pressed into hollow cavities of bodies and fit so closely, as to form a perfect cohesion, so as to exclude all air; and any power then to disengage them from bodies immersed, must be equal to the pressure of the atmosphere. The particles of water penetrate into minute receptacles, not obvious to human eyes,—into the pores of the most compact bodies, as of stone, &c.; and the particles being round and the cavities hollow, closely unite; and they adhere from the pressure of the atmosphere in consequence of the air being excluded from behind the particles, or from between the particles and the cavities; and no surface can be made so smooth and compact by human art, but will have minute recesses, capable of receiving particles of

water;—its penetrating power is equal to that of air, and even greater, since its fluidity is the same, and its specific gravity greater.

The friction on bodies moving in water can arise but in a partial degree, in consequence of the adhesion of the particles of water to the surface of the bodies; since there can be no cohesion of the particles to the surface, except in the minute cavities of the surface: the friction arises as well from the obstruction which the water meets with from the projecting parts of the roughness, or eminencies on the surface of the body.

In consequence of the adhesion of the particles of water in the hollow receptacles of a ship's bottom, the particles next to them meet with an obstruction when the vessel is in motion, and cause a friction one against the other. The particles also meet with an obstruction from the projecting parts of the roughness of the bottom, whereby a friction is created. And the particles of water obstructed, attract those contiguous to them: hence the water immediately next to the bottom of a vessel, from these obstructions and this attraction, is carried along with the vessel, and drawn from and moved against the surrounding water; and there is, in consequence, an attrition of one body of water against the other in passing each other, and a consequent friction. But the water which is drawn with the vessel, can only accompany her with a part of her velocity; since the friction of the attracted water against the surrounding water, operates to draw the former from, and to give it a motion from the vessel: therefore, the water which is drawn with the vessel, only accompanies her with a part of her velocity.

The friction on the bottoms of ships, therefore, arises from various causes; from the particles of water passing those which adhere to the hollow parts of the bottom; also from passing over the projecting parts of the roughness of the bottom; and from the attraction of one body of water against another.

A ship that is very rough and uneven in the surface of her bottom, will therefore meet with more friction than another which is smoother, although the form of both bottoms are alike; and the friction being caused by the velocity of the ship through the water, and from the close contact of the

water against every part, operates on the bow, on the midship-part, and on the after-bodies of ships, and much the same on every part of the bottom immersed—depending on the velocity of the surface past the water. It must, however, be observed, that at those parts of the after-body where dead water is formed, the friction may be less, because in that case there is only that part of the friction which is caused by the attrition of the closing water against the dead water, the latter having no motion against the surface of the bottom.

In all cases, the smoother the bottoms of ships are made, the less will be the friction. If, indeed, a ship's bottom could be made perfectly smooth, and so compact as to exclude the particles of water, then there would be a degree of repelling power, and the friction would be almost insensible. But no surface can be made sufficiently smooth and compact by human art. A globe of the finest and most polished glass floating on the water, and twirled round with the utmost force, will shortly cease its revolutions, not so much from the effect of its weight on the water, as from the friction of the water against the roughness of the glass (however, to appearance so smoothly polished), and against the particles adhering to the cavities in its surface; and an atmosphere of water, from the consequent attraction, may be seen to accompany it in its revolutions, in a slower degree, and the water agitated with a whirling motion to a considerable distance around it.

The greater the velocity of a vessel, the greater is the force with which the particles adhering to the bottom, and with which the projecting parts of the roughness of the bottom strike the water; and the greater therefore the velocity of the attracted water which accompanies the vessel; and consequently the greater the attrition of one body of water against another: therefore the faster a vessel moves through the water, the greater will be the friction.

Furthermore, as the weight and form of the particles of water are the same at every depth, and there being no adhesion among the particles, they are moved one against another with the like ease at every depth; and, therefore, although the pressure of water increases at different depths, according to the

height of the surface, above any particular depth; yet the difference in the pressure of the water can make no difference in the fluidity, or in the friction of its particles, nor in the adhesion of the particles to the cavities in the surface of bodies, since that is caused by the pressure of the atmosphere: the increase of the pressure of water does not increase the friction; the friction depends alone on the velocity of the surface of the body through the water, and the smoothness of that surface. The friction of water against a body is, therefore, the same at every depth, and it varies only with the rate of the velocity of the body passing through it.

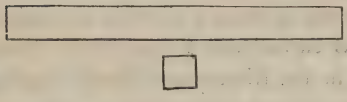
If two bodies (parallelopipeds) as delineated in TABLE XVI. equally smooth, of the same breadth and thickness, and of the same form, and alike in every respect, *except in length*, are drawn through the water with the same power or weight; it follows, that whatever difference there is in their velocity, it must arise from the difference in their length alone; since the direct resistance, and the suction in both cases are the same; and being exactly alike in the breadth and depth, and form of the bow and stern-ends; and in every other respect, *excepting in length;* and the *longest* body obtaining the *least* velocity; it therefore arises from the impediment of the friction against the *augmented length* of the surface of the longest body, over and above that of the shortest body. And therfore the *additional* weight required to give the longest body the same velocity as the shortest one, must be the power or weight required to overcome the friction on the augmented length. In this manner the friction is ascertained, as set forth in TABLE XVI.

It is evident, that the longer the body is, the greater the friction becomes; and the shorter the body is, the less the friction; and that the latter obtains, in consequence, greater velocity, with equal power or weight, than the former. But then it must be observed, that although length of body increases friction, and impedes velocity, yet as the capacity of a ship is increased by length, more power can in consequence be applied; she would be enabled to carry more sail, to force her through the water. The advantage obtained by this is, beyond comparison, greater than the impediment from this additional friction.

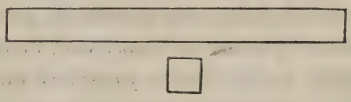
TABLE XVI.

EXHIBITING the power or weight, required to overcome the friction of the water against a superficial foot of a body, the superficial foot being in a direction parallel with the line of motion. The bodies described are smooth, and moved through the water both close below the surface, and also at six feet depth and at different velocities; and each two are alike in all respects, except in length: and the additional weight required to give the longest body the same velocity as the shortest, is the weight required to overcome the friction; and the proportion of friction for one foot of the surface, is that which is stated.

Immersed close below the surface.



Immersed six feet below the surface.



Velocity.		Weight required to overcome the friction of one foot of surface.	Weight required to overcome the friction against one foot of surface.
Miles per hour.	Feet per second.		
about	ft. dec. pts.	ounce.	ounces.
$1\frac{1}{2}$	2,54		$0\frac{1}{2}$
$2\frac{1}{4}$	3,66		1
	3,77		1
$2\frac{1}{2}$	4,07	$1\frac{6}{16}$	
3	5,18		$1\frac{1}{8}$
	5,27		$1\frac{14}{16}$
$3\frac{1}{4}$	5,62	$2\frac{12}{16}$	
$3\frac{3}{4}$	6,25		2
4	6,53		$2\frac{3}{8}$
$4\frac{1}{4}$	7,13		$2\frac{9}{16}$
	7,23	$3\frac{2}{16}$	
$4\frac{1}{2}$	7,59		3
$4\frac{3}{4}$	7,90		$3\frac{1}{16}$
5	8,54		$3\frac{14}{16}$
	8,59		$3\frac{5}{16}$
$5\frac{1}{4}$	8,74	$4\frac{13}{16}$	
$5\frac{1}{2}$	9,39		$4\frac{7}{10}$
$5\frac{3}{4}$	9,79	$5\frac{3}{16}$	
	9,81		$4\frac{1}{16}$
$6\frac{1}{2}$	10,77	$4\frac{9}{16}$	
	10,87		5
	10,92		$5\frac{1}{16}$
$7\frac{1}{4}$	12,05	$5\frac{8}{16}$	
	12,28		$6\frac{14}{16}$

The quantum of friction on bodies will be much the same, whether they have sharp or blunt entrances, if their length is the same.

The friction increases with the increase of the velocity of bodies; the greater the velocity of a vessel through the vater, the greater the friction becomes.

It will be seen, by referring to TABLE XVI. that the friction on one superficial foot of surface, placed in a direction parallel with the line of motion, is equal to the weight of one ounce, when a body is moved through the water at a velocity of $2\frac{1}{4}$ miles per hour. When moving at a velocity of $4\frac{1}{4}$ miles per hour, it is equal to three ounces; and at a velocity of $7\frac{1}{4}$ miles per hour, it is equal to $6\frac{1}{16}$ ounces weight.

Friction does not increase at greater depths in water; at least in motions under $6\frac{1}{2}$ miles per hour; and, indeed, it is extraordinary that there should appear by the TABLE to be any variation in the friction at different depths: it most probably arises from the difficulty of making correct experiments on bodies, when forced with velocity through the water, close below the surface.

It appears, however, by TABLE XVI. that there is some difference in the friction of water at different depths, but this is very inconsiderable, and it varies; appearing greater on the body when moving at the *surface* in *slower* motions, and greater on the body when moving at *six feet below* the surface in *quicker* motions. It further appears by the TABLE, that the friction is greater near the *surface* of the water than at six feet below it, when the bodies are moving at velocities *under* $6\frac{1}{2}$ miles per hour; and that the friction is greater at *six feet* below the surface of the water, than it is close below the surface, when the bodies are moving at velocities *above* $6\frac{1}{2}$ miles per hour.

And, moreover, that the quantum of increase of friction, from an equal increase of velocity, is rather greater at six feet depth than it is close below the surface of the water. But these variations may easily arise in making experiments; it appears reasonable to conclude, that the friction is the same,

at every depth, and varies only with the difference of the velocity of the water past the surface.

It has been observed, that the smoother the bottoms of ships are made, the less will be the friction; and, of course, the better they will sail; this also experience invariably confirms. Ships when they have been long at sea, and their bottoms get covered with barnacles, do not sail near so fast. In these cases, the impediment from friction is oftentimes so great, as to become equal to the impediment of the total resistance of the body, when she first commenced her voyage. For instance, a ship requires double the power to force her through the water ten and a half miles an hour, as she does seven and a quarter miles an hour; and there is quite as much difference very often in a ship's sailing, when her bottom is foul, and when it is clean.

It is by means of the particles of water adhering in the minute hollow cavities of the surface of ships' bottoms, that the polypus, and other marine vegetation, are first attached to their bottoms; forming at first a slime, and then a vegetation; which soon grows to a length to occasion a great impediment to the ship's velocity. To this vegetation the barnacles and the muscles afterwards attach themselves. From all these collections, the friction becomes at length a *principal* impediment to the velocity of ships; whereas, in the first instance, it is not so material an obstruction, when compared with the total resistance.

CHAPTER II.

On the Increase of Friction, from the Increase of Velocity of Bodies through Water.

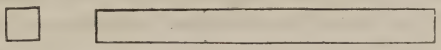
THE friction of water on bodies increases with the increase of the velocity, in a greater proportional rate, than the proportional rate of the increase of the velocity itself: that is, the friction increases more than double as much, with double the rate of velocity; more than triple as much, from triple the rate of velocity, &c. &c.

This is detailed in TABLE XVII.; where it will be seen, that the friction increases to three times as much, from double the rate of velocity; to six times as much, from triple the rate of velocity; and to ten times as much, from four times increased rate of velocity.

It may be observed, that the increased rate of the friction, is not so much above the increased rate of the velocity, as the increased rate, which either the resistance or the suction has above the increased rate of the velocity; this may be seen by reference to TABLES VI. and XII. For the resistance increases to *four* times as much, from double the rate of velocity, to *nine* times as much, from triple the velocity; and to *fifteen* times as much, from four times increased rate of velocity; and the suction, when exerting its full power, on bodies with square stern-ends, is nearly in the same proportions. There is, therefore, a peculiarity in the nature of the obstruction from friction; not only varying from the general laws of the resistance of fluids, but also from that of water against bodies, as ascertained by experiment: and one of the causes of the variation of *the latter*, from the general laws of the resistance of fluids, arises from this peculiarity of the obstruction from

TABLE XVII.

SHEWING in what proportion the impediment to velocity from the friction increases, when bodies are moved through the water with double, triple, or quadruple, increased rate of velocity.—The friction against one superficial foot of surface, placed parallel with the line of motion, is stated as follows :—



Increased rate of velocity.	Velocity, feet per second.	Immersed close below the surface.		Immersed six feet below the surface.	
		Weight required to overcome the friction.	Increased proportion.	Weight required to overcome the friction.	Increased proportion.
Nearly	ft. dec. pts.	Ounces.		Ounces.	
	2,54	.....	.....	.... $0\frac{1}{2}$	Three times.
	5,18	.....	.....	.... $1\frac{1}{2}$	
	3,77	.....	....	 1	Three times.
	7,59	.....	.....	 3	
	4,07	.... $1\frac{1}{12}$	Four times and a half.		
	8,74	.... $4\frac{13}{16}$			
Double	5,27	.....	.....	.... $1\frac{11}{16}$	Three times.
	10,87	.....	.....	 5	
	5,62	.... $2\frac{13}{16}$	Twice barely.		
	10,77	.... $4\frac{9}{16}$			
	5,62	.... $2\frac{13}{16}$	Twice.		
	12,05	.... $5\frac{9}{16}$			
	6,25	.....	.....	 2	Three times full.
	12,28	.....	.....	.... $6\frac{14}{16}$	
	2,54	.....	.....	.... $\frac{1}{2}$	Six times.
	7,59	.....	.....	 3	
	3,66	.....	.....	 1	Near six times.
	10,92	.....	.....	.... $5\frac{11}{16}$	
Triple	3,77	.....	.....	 1	Near seven times.
	12,28	.....	.....	.... $6\frac{13}{16}$	
	4,07	.... $1\frac{1}{12}$	Five times.		
	12,05	.... $5\frac{9}{16}$			
	2,54	.....	.....	.... $\frac{1}{2}$	Near nine times.
	9,81	.....	.....	.... $4\frac{5}{16}$	
Four times	2,54	.....	.....	.... $\frac{1}{2}$	Ten times.
	10,87	.....	.....	 5	

friction, since the whole weight, to give velocity, acts in part to overcome the friction.

This peculiarity in the obstruction from friction, arises from the causes which create friction. Friction arises from the impediment which the particles of water meet with, against the eminencies or roughness of the surface of the body; and from the impediment which those particles of water, disengaged from the body, meet with, from their collision against those particles, which adhere to the cavities of the surface; and also from the attrition of the attracted water against that surrounding it.

Now, the roughness of the surface of the body remains the same; and the adhesion of the particles of water cannot be at all lessened by the velocity of the body, since the pressure of the atmosphere continually acts upon them. When the body is in motion, the particles adhering to the surface, in the cavities, meet with an attrition from those particles next to them; for the particles, from being globular, cause a greater inequality in their surfaces, when in contact, than if one surface was round and another flat; and there must also be a greater difficulty in moving one particle against the other, when one is fixed, than when both are disengaged. The motion of the attracted water against that contiguous to it, differs therefore in this respect; both parts thereof being always free and disengaged, and in a state of fluidity, and with the utmost facility yielding to every pressure.

This part of the friction does not, therefore, vary or increase so much with increase of velocity, since the obstruction from the collision of the particles, arises from the action of water against itself, free and disengaged, and yielding every way; and it is only that part of the friction, arising from the obstruction of the water against the particles fixed, and against the eminencies of the roughness of the surface, which increases with increase of velocity, at the same rate as the resistance and the suction. And hence arises the peculiarity of the friction before adverted to; and this makes it more clear, that the friction arises from the obstruction of the particles against the

projecting parts of the unevenness of the surface of bodies, and from that of the particles in the minute cavities of the surface, and from the collision of the water carried with the body (in consequence of these obstructions) against the surrounding water.

Although friction operates on every part of the bottom of a ship, on the bow-end, on the midship-part, and on the stern-end, yet, as has been before observed, with respect to the stern-end, there must be less friction at such parts of the stern-end, where any dead water is collected, since the motion of the water against such parts of the surface is entirely suspended by the suction. On the other hand, if the stern-end of a vessel is longer than is required, for the water to close against it with full effect to do away the suction, the vessel will meet with an impediment to her velocity, from the friction against that part of the stern-end, which is longer than is necessary.

Thus the proper length of taper of the stern-end of vessels, in order to avoid suction, depends partly on the velocity of the body through the water: for instance, two bodies having the same midship-part and bow-end, but different length of stern-ends; *viz.* this with three feet stern-end, and this with four feet six inches stern-end:

when these two bodies are moved through the water, at the rate of two miles an hour, the one with the longest stern-end requires rather the most weight; but when moving at the rate of eight miles per hour, the one with the shortest stern-end requires the most weight.

This shews that, at the slowest rate of velocity, the shortest stern-end is long enough, in order to avoid suction; and at the quickest rate of velocity, the shortest stern-end is not long enough to avoid suction. It shews also, that as the longest stern-end requires the most weight, to obtain the slowest rate of velocity, that it must arise entirely from the additional *friction*

on the greater length, since the suction cannot, in this case, be greater on a longer stern-end than on a shorter one.

And, as the impediment to velocity in quick motions, arising from the suction, in consequence of shortness of taper of stern-end, is so very much greater than that which arises from the additional friction on a longer taper, the friction cannot, in such cases, deserve a consideration. The taper of the stern-end of ships should be made, if any thing, rather longer than needful, to avoid suction, when ships are sailing at their greatest rate of velocity.

CHAPTER III.

On the Comparative Proportion of the Impediments to Velocity, between that of the Direct Resistance and of the Suction, and of the Friction, as they operate on Ships.

IN order to take a comparative view of the resistance, and of the suction, and of the friction of water, on the bodies of ships, TABLE XVIII. describes the figure of a body, very similar in its proportion with the immersed part of the bottoms of ships, by which practical inferences may be drawn, and useful observations made.

It will appear, that the resistance becomes four and a half times greater with double the increase of velocity; the suction three times greater, and the friction three and a quarter times greater, with double the increase of velocity. The friction forms a less proportion of the whole obstruction to velocity, when the body is moving at quicker than at slower velocities.

The friction forms a greater proportional part of the whole obstruction to velocity, than the suction does; the friction being twice as great an impediment to velocity as the suction; *viz.* the former being about a twentieth part of the total resistance, and the latter about a forty-eighth part.

It must be observed, that the friction on the bottom of ships is never in so small a proportion as stated in the TABLE, excepting when the bottom is very smooth, and free of any slime, vegetation, &c. &c. When the bottom is very foul, from these collections, then the friction forms a very great proportion of the whole obstruction. In extraordinary cases of foulness of bottom, the friction may become even as great an impediment to the velocity of ships, as that of the direct resistance, and the suction united.

TABLE XVIII.

EXHIBITING in a comparative view, the proportions which the resistance, the suction, and the friction, bear to each other, in their operation on the bottom of ships, to impede their velocity. The *Figure* described being of nearly the proportional dimensions of the immersed part of the bottom of a ship, and moved through the water at six feet depth, having one foot area of surface of resistance, and fourteen feet of surface for friction; *viz.* that on its sides and bottom part.

Velocity of body.	Weight required to overcome the direct resistance, exclusive of suction and friction.	Total resistance or weight required to overcome the direct resistance, the suction, and the friction altogether.	Weight required to overcome the suction alone.	Proportion of the suction to the total resistance.	Weight required to overcome the friction alone.	Proportion of the friction to the total resistance.
Miles per hour.	lbs.	lbs.	lbs.	part.	lbs.	part.
$2\frac{1}{2}$	$14\frac{1}{10}$	$15\frac{5}{10}$	$0\frac{4}{10}$	$\frac{1}{38}$	1	$\frac{1}{16}$
3	$21\frac{2}{10}$	23	$0\frac{6}{10}$	$\frac{1}{38}$	$1\frac{3}{10}$	$\frac{1}{19}$
$3\frac{1}{2}$	30	$32\frac{5}{10}$	$0\frac{8}{10}$	$\frac{1}{40}$	$1\frac{7}{10}$	$\frac{1}{19}$
4	$39\frac{8}{10}$	43	1	$\frac{1}{43}$	$2\frac{2}{10}$	$\frac{1}{19}$
$4\frac{1}{2}$	$51\frac{8}{10}$	$55\frac{6}{10}$	$1\frac{2}{10}$	$\frac{1}{46}$	$2\frac{6}{10}$	$\frac{1}{21}$
5	$64\frac{5}{10}$	69	$1\frac{4}{10}$	$\frac{1}{49}$	$3\frac{1}{10}$	$\frac{1}{22}$
$5\frac{1}{2}$	$79\frac{9}{10}$	$85\frac{4}{10}$	$1\frac{6}{10}$	$\frac{1}{53}$	$3\frac{9}{10}$	$\frac{1}{24}$
6	$94\frac{7}{10}$	$100\frac{7}{10}$	$1\frac{7}{10}$	$\frac{1}{59}$	$4\frac{1}{10}$	$\frac{1}{24}$

It will be seen by the TABLE, that the suction forms a much less proportion of the whole obstruction, in quicker than in slower motions.

But then it must be observed, that when the stern-end is shorter than the one described in the TABLE, the suction forms a greater proportion of the obstructions in quicker than in slower motions, and, in some cases, much greater; for instance, by referring to TABLE XIV. where the stern-end of *Figure* A, is only half as long as that of the *Figure* in TABLE XVIII. the suction of *Figure* A, when the body is moved at a velocity of two and a half miles an hour, is equal to one-*ninth* part of the resistance; but when moved at a velocity of six miles an hour, it then becomes equal to one-*sixth* part of the resistance.

The *Figure* in TABLE XVIII. has a taper of stern-end, in a medium degree to the taper, and diminishing of the after-bodies of ships, at different depths under water. But the after-bodies of ships, toward the surface of the water, has often as little diminish as *Figure* A, being fuller at the surface than lower down; and therefore the suction of that part of the stern-end of ships, towards the surface of the water, becomes much more increased, from increase of velocity, than that of the stern-end of the *Figure* in TABLE XVIII: For instance, the suction of *Figure* A, becomes five times greater, from double increased rate of velocity, and that of the *Figure* in TABLE XVIII. three times only.

Referring to TABLE XVIII. it will be seen that the resistance is twenty times greater than the friction, and forty-eight times greater than the suction. The principal of the impediments to velocity is, therefore, the immersed part of the midship-section and its area. In order, therefore, to form bodies to obtain the greatest velocity, the most important object is to contract or lessen the area of the midship-section as much as possible; and to do this, and at the same time to obtain a sufficient bulk or capacity, the only effectual means is to *lengthen* the midship-part. The next material object is, to give the stern-end a sufficient length of taper, in order to avoid suction; and *length* is the only means to be resorted to, for this purpose. And the next important consideration is, to form the bow-end of a sufficient length

or acuteness, so as to divide the water with the greatest ease and facility; and *length* is the only means also to be resorted to for this purpose. On every consideration, therefore, length of body is absolutely indispensable to velocity: length of bow-end lessens resistance; by length of midship-part, the area of the surface of resistance may be lessened; and by length of stern-end the suction avoided.

And in regard to friction, although length of body adds to friction, yet that is of no comparative consequence; a smoothness and compactness of surface must, however, be observed, to lessen friction; and every means to preserve the bottoms of ships in this state, during long voyages, becomes of much consequence; since, when the bottom is very foul, the friction becomes a material impediment. Nothing yet made use of with this view, is to be compared with copper; the coppering of the bottoms of ships may be considered, in regard to ships, as one of the greatest improvements of the age; but then the copper should be laid on very smooth, and the heads of the nails not project; the copper should be cold rolled, to give the surface compactness; and it should be pure copper, without mixture of iron, or other metallic substances; for these being corroded, and soon destroyed by the copper, occasion the surface to become filled with cavities and eminencies, and this increases the friction considerably.

Two ships having the same area of surface of resistance of midship-section, but one being longer than the other, the short ship will have less *(vis instita)* force to steady her motion than the long ship (or, as the mariners term it *to keep her way*), through the water; the long ship being heavier, has a greater power to persevere in her motion, and in continuing it at those intervals, while the power which causes her motion may, from any circumstances, be alternately varied or diminished; such as from the irregularity of the impulse of the wind on the sails, as also in overcoming any partial obstructions from the waves. The advantage of the weight of the long ship, in this respect, is similar to that of a heavy fly-wheel in steadying the motion of a machine. Moreover, the long ship having greater capacity, has, generally speaking, a greater power of carrying sail, and of augmenting its force to overcome the resistance, and increase its velocity.

When ships with similar fore and after-bodies, and of equal area of resistance of midship-section, but of a different length of midship-body, or of capacity, are under sail; the water will oppose each ship equally, so that they will have equal resistances; but then, they will have different powers of carrying sail to overcome that resistance, in proportion to their respective capacities; and their velocities will be to each other, as the power which each ship has in carrying sail, or to the quantity of sail each ship carries.

When ships with similar taper of fore and after-bodies have different length of midship-body, so as to have precisely the same capacity, but different areas of surface of resistance of midship-section, when such ships are moved through the water with the same power, their respective resistance will be nearly in proportion to the area of the immersed part of the midship-section of each, and their velocities will be according as the same power is, to their resistances respectively. Thus, if the midship-part of one ship, is made so much longer than another, as that the area of the immersed part of the midship-section of the one, is only one-half of that of the other, and yet both ships have the same capacity, the resistance of one ship will be only about one-half of that of the other. The capacities of ships should, therefore, be increased (as much as can be, with a view to safety,) by length; and also by a due fulness of the fore and after-bodies, and by the area of the surface of resistance of the midship-section being diminished as much as possible. But, nevertheless, in all cases the contour, or form of the fore and after-body; that is, the length of taper, and form of curve, should be such as to enable the ship to divide and pass through the water with the utmost ease, when going at her greatest rate of velocity.

CHAPTER IV.

On the Difficulty of forming any regular Laws, applicable to the Resistance of Water against Bodies of similar Form to those of Ships, moving at the Velocities they usually sail at, and at the Depths in Water to which they are immersed.

IT will have been seen that the impediment to the velocity of a ship, arises from the resistance of the water against its bow and area of midship-section, from the suction at the stern-end, from the friction of the water against the part immersed, and from the action of that water which accompanies a ship in its motion, against that at rest contiguous to it.

By taking a comparative view of the theory of the resistance of fluids with the resistance of water, as per experiment, against bodies moving near its surface, and at the velocities ships usually sail at; it appears, that the resistance against a plane surface is less by experiment than by theory, and that the resistance against an oblique surface is much greater by experiment than by theory; and that it does by no means follow the law of the sine of the angle of incidence. And further, that the difference between the velocity of a body having an acute bow-end, and of one having a full-curved bow-end (both bodies being alike in all other respects), becomes less and less, the faster the bodies are moved through the water; for a body with a full-curved bow-end obtains a velocity of fifteen miles an hour, with the same propelling power as it would do if it had an acute bow.

Again, the resistance of water against a body when moving at certain velocities, is found by experiment to be less near its surface than at greater depths; and the difference of the resistance at different depths, to depend on the rate of the velocity of bodies through the water, and also on the form

of the bow-end of bodies; but at a velocity of thirteen miles per hour, the resistance at six feet depth; and at close below the surface, is the same against the same bow-end, whatever may be the form of the bow-end. Nor is the resistance of water against a body, found by experiment to be as the square of its velocity, according to the theory: and it varies also differently at different experiments; as, when bodies are moved at different depths, and when they have different formed bow-ends; and also different formed stern-ends; and also when bodies are moved at different rates of velocity; and this latter owing to the form of the stern-end.

There are also found to be peculiar circumstances attending the resistance of a body not wholly immersed (as is the case with ships); it meets with more resistance than if wholly immersed; for the water, not being able to pass over the body, is by the force of its velocity raised above the level against the body, and which causes greater resistance. And further, a broader area of plane surface opposed directly to the water, and not wholly immersed, meets with more resistance than a narrower surface, in proportion to the difference of breadth; the water, by the force of the velocity of the body, is raised above its level, and highest above its level at the middle of the plane; and the broader the surface of the plane, the higher the water is thus heaped up at the middle of the plane.

The suction at the stern-end of bodies has also peculiar variations in its effects; which causes the velocity of a body to differ by experiment, from the theory. It is found by experiment, that the greater the velocity of a body through the water, the longer the taper of the stern-end is required to be, in order to prevent suction; and the longer the stern-end is made, the less the suction increases with increase of velocity, to what it does with a shorter stern-end; and the more curving the stern-end is made, the more the suction increases with increase of velocity, than when less curving. And as the velocity and collapsing power of water in closing against the tapering stern-end of bodies increases with its depth, a body when moving at greater depths does not require so long a taper of stern-end, as when moving nearer the surface. And thus the due length of taper of a stern-end, in order to avoid suction, depends on the depth a body is moving

in the water, as well as on the velocity of a body; and consequently, the velocity of a body with a certain length of taper of stern-end, may be greatly impeded by the suction, when moving at greater velocities, or nearer the surface of the water; but, when moving with less velocity, or at greater depths, it may meet with no impediment whatever from it; and thus the motion of the same body, having a tapering stern-end, is retarded by the suction when moving at one velocity, and not at all when moving at another velocity; and retarded by it, when moving at one depth in water, and not at all impeded when moving at another depth. These, and other circumstances relating to the suction, occasioning an irregularity in the motions of bodies with tapering stern-ends (such as that of a ship), when moving at increased rates of velocity, are partial causes why experiment does not accord with the law, of the resistance to a body being as the square of its velocity.

The friction of water on bodies, is found by experiment to increase less with increased rate of velocity, than the direct resistance, and differs more widely from the law just adverted to: nor does the friction operate at all on those parts of the tapering stern-end of bodies, to where dead-water is attached by the suction, at the time when bodies are moved at greater velocities to occasion dead-water; but when bodies are moving at lesser velocities, and there is in consequence no dead water, the friction then operates on those parts.

And, further, as the water accompanies a body in its motion, and the body passes through the water immediately next to it with less velocity than it moves forward, the comparative velocity with which a body passes through the water immediately next to it, in proportion to the whole velocity at which it moves forward, depends, on the form of the body, on the smoothness or roughness of the surface of the body, on the rapidity of its motion, and (it is submitted) on the depth, at which the body may be moving in water. And the great velocity of water, in closing on the tapering stern-end, being caused by the overpowering force of gravity and weight of the water, must occasion a considerable diminution in the velocity of that part of the water, accompanying a body in its motion, which is opposite to the stern-end.

The comparative velocity with which a body passes through the water immediately next to it, in proportion to the whole velocity at which it moves forward, depends on various circumstances; and the action of water against itself, at different velocities, is not easily to be calculated upon. The friction and suction (on the tapering stern-end of bodies) increases much less with increased rate of velocity, than the resistance according to the theory. The friction is (as has been shewn) partly the action of the water against itself; and the suction at the tapering stern-end of bodies is also operated upon by the action of the water against itself. It becomes questionable, therefore, whether that part of the resistance, occasioned by the tenacity and friction (or the action) of the water accompanying a body in its motion, against that contiguous to it, increases exactly according to the square of the velocity.

Another circumstance presents itself:—Water, near its surface, is affected by the state of the atmospheric air; and inasmuch as the proximity of its particles may depend on the heat or temperature of the air, a difference in its resistance will accordingly arise: as will the suction also be increased or diminished according to the heavier or lighter state of the atmosphere.

So many partial effects occur, in respect to the resistance of water against different formed bodies moving at and near its surface, and at the velocities ships usually sail, that it is obviously no easy matter to devise regular laws applicable thereto; but, by thus ascertaining and pointing out the intricacies and difficulties in the way, it is hoped some light is thrown to further the progress of the science.

It is further submitted as probable, that, when bodies are moved at extraordinary rapid velocities (very much greater than those which ships sail at), and at great depths in water; and when the suction operates with its full atmospheric effect, and the friction in its due degree; and when the water acts, in all respects, with its natural power, in regard to its total resistance; and no partial effects whatever occur:—that the present theory might be

found to be nearly correct in many respects; and, perhaps, nearly so in most respects, if a body, when moving at such great velocities and depths, actually divided and passed through the water, with the same velocity it moved forward. And (when a body is moving at such great velocities and depths) even supposing the water should then accompany it in its motion; so that it passed through the water immediately next to it, with less velocity than it moved forward; or, even supposing a body should not then divide the water at all; but the resistance become that of an atmosphere of water accompanying a body in its motion moving against the water at rest, and contiguous to it; it is submitted, that the present theory might, in either case, be found to apply in many respects. And it is founded on a grand and broad basis, to afford general ground for support under doubts and difficulties; and, upon the whole, is so extremely important, that we are irresistably lead, if not wholly to rest upon it, at least to lean to its support, in all our researches on this important subject.

A USEFUL TABLE OF VELOCITY.

Miles per hour	are feet per second.	Miles per hour	are feet per second.	Miles per hour	are feet per second.
1	1,690	4½	7,609	9½	16,063
2¼	2,113	4¾	8,031	10	16,909
1½	2,536	5	8,454	10½	17,754
1¾	2,953	5¼	8,877	11	18,600
2	3,381	5½	9,300	11½	19,445
2¼	3,804	5¾	9,722	12	20,290
2½	4,227	6	10,145	12½	21,135
2¾	4,650	6¼	10,568	13	21,980
3	5,072	6½	10,991	13½	22,825
3¼	5,495	7	11,836	14	23,670
3½	5,918	7½	12,682	14½	24,515
3¾	6,340	8	13,527	15	25,360
4	6,763	8½	14,372		
4¼	7,186	9	15,218		

BOOK II.

CHAPTER I.

On the extraordinary rapid Decay of our Men of War, and the Causes pointed out.

NO subject can be deemed of greater national importance, nor any which at this time more imperiously demands attention, than the present state and condition of our navy.—The rapid decay of our men of war, and the consequent enormous expense of upholding a navy so prodigious, is a calamity to be deeply deplored, particularly at this time of financial difficulty.

It is an alarming truth, that our ships have become more subject to decay of late years than at any former period; more so even than they were about two centuries ago.

On considering the matter minutely it will appear, that the calamity in our time has arisen from a variety of causes, but chiefly from the condition and quality of the materials with which the ships have been built. The number of our ships has been doubled within these few years. The pressing wants for the navy during the late war, was with difficulty provided for by any means. There was no choice in the quality of the materials. The misunderstanding with the Northern Powers of Europe obliged us to resort to our American colonies for supplies; and the materials from thence have unfortunately been found of a most perishable nature: but what is still further to be deplored is, that those materials have not only themselves rotted, but

have communicated decay to timber of greater natural durability, and caused to rot, with themselves, immense quantities of our British oak.

The recourse to our own Colonies was certainly an unavoidable alternative; and, indeed, putting the quality of the materials out of the question, it must be allowed to be a wise policy, to have recourse to our own Colonies for supplies, in preference to the markets of foreign powers.

Our country, at an enormous expense, has, with these perishable materials, made a mighty effort to accomplish its future and permanent prosperity, and has succeeded most triumphantly. Let it not, however, be said, that the British navy, riding triumphant on the ocean, is in a perishing condition. The means of our naval superiority must not, cannot, be lessened. Our utmost care and attention should now be given to put our ships in a sound condition, and to preserve their duration by a steady wise system at the least possible expense, and to investigate most minutely *every cause* of the unprecedented decay in our ships. When we witness the same description of materials to last so much longer in merchant vessels than in our men of war; and the same description of materials, when used in houses and public edifices, to be of much greater durability; it would appear that there must be causes, both various and peculiar, for the present decay of our navy.

Before entering particularly into the various causes, it may be proper briefly to advert to them. Experience has long shewn that ships, constructed with a mixture of timbers, have been of a shorter duration. It always happens, that the materials which goes first infects and destroys those in contact with them. The oaks of North Europe being of quicker decay, will destroy our own native oak, when used in contact therewith, in one-third of the time of its own natural durability, or when used by itself. The oak and fir of Canada is still more perishable in itself, and more destructive to our native oak, than even those of North Europe. By looking to the history of the French marine it will be found, that the use of the timber from Canada, while that country was in their possession, proved destructive to their ships also. The decay of our own navy was certainly never so great before these materials were introduced into the ships.

But our native oaks have undergone a change; acorns from abroad, particularly from America, have been sown in this country. The landed proprietors find it more advantageous to use them, because of their producing trees of a quicker growth than the oak from the native acorn. The timber from foreign acorns, has become now of a fit size for ship-building, and much of this spurious material has been used under the denomination of English oak.

The materials are also used in an improper state, as will be pointed out hereafter. And timbers taken out of old ships are frequently used again in repairing and building new ships: and such old timber, it is to be feared, are often infected (though invisibly) with the dry-rot. There is also introduced, timber unseasoned, which, being afterwards closely pent up in the ships in stagnant air, their vegetable juices become putrid and corroding, and produce rapid decay. The sap on the edges and sides of some of the timbers and planks in the ships being left on, the fringe is introduced; and this, after destroying the sap, commences its destructions on the heart of the timber. Boiling plank and thick stuff in water, in order to make it supple and pliable to bend to the timbers of the ships, is not only highly injurious to the materials, from the fibres of the wood being over distended and weakened by the boiling water, but leaves it in a more porous state, and more open to the admission of putrid matter from the damp stagnant air in ships, which generates decay:—a preferable mode will be shewn. The use of iron for bolts and nails, has also a very pernicious effect in our ships; the acidity of our oak, and the salt of the sea-water, both corrode the iron: and the wood around the iron decays in consequence. The Romans did not, formerly, nor do the Chinese now, use a particle of iron in constructing their vessels. The use of pitch and tar in ships, is exceedingly injurious to the iron and copper to which it attaches. In the East Indies, at the Brazils, and in China (the vessels of which countries are of the most durability), neither pitch nor tar is used, but other compositions far preferable, some of which are easy to be obtained.

Painting the interior of a ship below the upper deck, has a most destructive tendency; it prevents air from entering the pores of the wood, and

moisture from evaporating through them. Thus, the wet and damps being pent up by coats of paint, undergo a change, turn putrid and corrosive, and decay is the inevitable consequence. Paint and putty, applied in those parts of the interior of a ship which are not exposed to the weather, can be but of very little utility, and is, moreover, a great expense. The want of a free circulation of fresh air through every part is materially injurious: the timbers are sawed die square, and put so close together as to exclude its admission: there should be no more of flat surface of timber against the plank than absolutely needful for the fastening; the edges of the timber should be rounded off, and the timbers placed further apart to give more space for the admission of air; for air must be considered of the utmost importance to the durability of ships. The practice of introducing and caulking fillings on the flat below, between the floors and futtocks, prevents the course of water through the openings: by the rolling of the ship the water would create a constant agitation of air in the frame, and tend greatly to preserve the timber: nor do these fillings so fully answer the purpose intended; an improvement could be made, whereby they would answer better, both for fafety and circulation of air, as will be mentioned hereafter. The exhalations from bilgewater, when ships are not pumped out frequently, are extremely noxious: pure water let in often has a very salubrious tendency, both with respect to the ship and the health of the crews; hence why leaky ships are found to be so sweet and healthy. The fœtid air from the warm breaths of a numerous crew, and from the filth and dirt below, the closeness of the different storerooms and cabins, and the want of a circulation of pure air, operates most destructively on our ships; and the wet pent up in the timbers in foul stagnant air changes its nature, and fills the pores of the timbers with putrifying and corrupt matter, and brings on that most fatal of all causes of the decay of our ships—the dry-rot.

Another cause of lessening their durability is, that of their having been built without shelter, exposed to rain, the heat of the sun, and to piercing winds, all which are highly prejudicial. In Sweden, Venice, and sometimes at Brest, they build their ships under covering; which on every consideration, whether in respect to the materials or workmanship, is extremely important. The Venetian ships of war are built under sheds sup-

ported by walls on each side, admitting only a moderate current of air. They also preserve their ships under cover, under which some of them have been known to remain near sixty years; when the timbers have been found to be shrunk only, but without any marks of decay.

Nor is there that care taken sometimes in the fair use of our ships; they are frequently suffered when abroad, to continue leaky in their upper-works, because the paint work should not be disturbed, and the ship disfigured by fresh caulking. The consequences of such neglect are injurious in the extreme (particularly in hot climates); for the rain-water penetrates the seams of the plank, and lodges between the timbers and the plank, by which decay quickly ensues.

The altered nature of the service is another cause of hastening the decay of our ships; for since the practice of coppering (which has not been generally adopted above forty years), the ships are enabled to continue abroad for three or four years without the necessity of coming home to be docked. By remaining out so many years in hot climates without the crews and stores being taken out, or the ships cleared of filth, and purified of stagnant and putrid air, decay takes its course without interruption. Before the practice of coppering our ships was introduced, they were obliged to come home more frequently to go into dock: and being then discharged of their crews, and the timbers cleared of filth and laid open and purified, the condition of the ships became renovated and their durability promoted.

But of all the causes which have produced the most rapid decay of our ships, not one has proved so fatal as the dry-rot. It may be compared to a mortification in the human system, as requiring immediate amputation; for the consequences of the dry-rot cannot be averted, but by removing at once all the parts infected: without this remedy decay makes its progress throughout the ship. The causes of this dreadful destruction are various; sometimes it arises from putrid matter, forming in the pores of the wood, either out of the natural juices or from water imbibed; some kinds of timber have a natural tendency to the dry-rot: other timber, though excellent in quality itself, is liable, from being used in an unseasoned state; for unless

the vegetable juices are exhaled by gentle warmth, and carried off by a moderate current of fresh air, the seeds of corruption generate in the wood spontaneously. The dry-rot may also be communicated to a ship, by introducing materials already infected; and this, it is to be feared, has often been done, by using timbers which have been taken out of old ships, in repairing and building others. Nothing is, indeed, more certain than, that wood decayed by any description of rot, placed in contact with that which is sound, will hasten the destruction of the latter.

Other causes of the dry-rot arise from the texture of the wood being injured. Timber that is water-soaked, being exposed to hard and long frosts, the pores of the wood become over-distended, and in that state remaining fixed, the elastic adhesiveness of its fibres, and their power of contraction, are destroyed. Timber in that porous state being afterwards confined in damp stagnant air, the interstices fill with putrid corroding matter, and dry-rot ensues, as will be exemplified hereafter. Other causes of the dry-rot are,—saw-dust, and other filth, left in the joints of timbers. The want of a circulation of fresh air, to prevent the damps, arising from the immersed part of a ship becoming putrid from foul air, and the warm breaths of so many men, and from the effluvia from the stores and provisions on board. All these, together with other circumstances, combine to cause and accelerate the dry-rot.

When once the dry-rot has taken place in a ship, its fatal effects cannot be prevented, but by taking out all the parts infected. The experiment now trying, with this view, by sinking ships infected with it in salt-water, for some months, may, possibly, retard its progress for the time; but, by the operation, the texture of the wood, with which they are built, will be injured by being so long water-soaked; and the ships afterwards, if in active service, become at once more extensively subject to its destructive effects, than before. The fastenings also will receive material injury. And, above all, great danger is to be apprehended to the health of the crews, and damage to the provisions and stores on board, from the damp state in which such ships must be in, for a long time after being taken out of the water. Houses, built with stone or mortar, saturated with salt-water, will continue

damp for years; and, without almost constant fires, furniture, linen, silks, &c. &c. will be continually damaging, from moulder, rust, and mildew.

Considering the different causes of the decay of our ships; it will be seen, that their durability depends upon,—the natural quality of the materials with which they are built; the condition of those materials, when used; the care taken in building the ships; and the treatment of them while in service.

Many observations present themselves, in regard to the nature and quality of timber. Trees, with small sap-vessels, are of slow growth, of close grain or texture, and of great durability. The closer the texture, the harder the fibres; and those trees, with large sap-vessels, are of quick growth, of an open, porous, or spongy grain, and of little durability. In most cases, the natural durability of timber may be judged of, by the size of the sap-vessels; for trees can only be considered vegetables of a larger growth, obtaining a superior size by the same means, heat and moisture, the grand stimulous of vegetation. The fibres also, of wood, are of different texture, some being harder than others: this is visible enough in old furniture, where the softer fibres have been rubbed away, and the harder ones left in ridges. And there is a perceptible gradation in the substance of trees,—from the hardest to the softest fibres, next to the sap; and, lastly, to the juices; similar to the bones, the flesh, and blood of animals. There is a like gradation in the durability of the several parts of wood: the hard parts endure the longest, and the soft go first to decay.—The vegetable juices in trees form a large proportion of their substance; for, when those juices are absorbed from a green oak, it loses nearly half its weight.

In different climates, trees are of a different nature. In cold climates, the timber is chiefly resinous, to resist and protect it from intense frosts; witness the whole tribe of pines. Under the torrid zone, where trees grow up, and are hardened by the hottest rays of the sun, they are protected from the scorching heat by the closeness of their texture; such, for instance, are the hard woods of the Brazils, the Havannah, the Floridas, Terra Firma, on the banks of the Amazon and Oroonoko, at Guayaquil, Baldivia, and the East Indies. Other trees in those climates, when of a porous and open

grain, are found to be oily and odoriferous; and this, to protect them equally from the heat and putrefaction in hot pestilential situations. Such are the teak, of Batavia, of Bombay, Bengal, and Pegu; the Santalum, also, of Malabar; the cedar of the Japanese, of Cuba, the Floridas, and the Bermudas.

In climates, where the extremes of heat and cold alternately prevail, resinous trees abound still more with turpentine, than in those parts where the extreme of cold only is felt; whereby they have always a sufficient quantity to protect them from the intense frost, notwithstanding the exudence of such of its turpentine from the heat of the sun. Such is the pitch-pine tree of the southern states of America, the spongy substance of which is saturated with turpentine, not only to guard it against the extremes of heat and cold, but also from the quick transitions of those extremes, occasioned by the sudden shifting of the wind, from the sultry south, to the cold north west; and in these parts the oak (the live oak) abounds with oil; nature commonly affording peculiar and proper sustenance and protection to trees, correspondent to the climate.

It must be further observed, that the timber of but few trees will last so long out of, as in its native climate. Timber grown in the northern regions abounding in turpentine, when afterwards exposed to the excessive heat of the torrid zone, the sun drawing out the turpentine, it dries up, and perishes, from the loss of its natural preservative; and, indeed, most of the European woods rend and dry up under the torrid zone, being commonly too soft to withstand the excessive heat.

The timber grown in hot countries, which, with care, endure for ages in its natural climes, if brought into the northern regions, and exposed to intense frost, do not last. The fibres of the timber, when water-soaked, become expanded, and over-distended with frost; and these ungenial operations being frequently repeated, occasion the timber, at length, to lose that firm adhesive state of its fibres; which, being forced into a porous state, becomes subject to dry-rot.—Intense frost acting upon timber, not of a resinous nature, even of the growth of the northern regions, occasions it to become porous, and of a soft

texture; and, consequently, such timber of these latitudes, as is not resinous, is commonly of little durability: hence, why the oaks, the elms, the beech, and the birch, of North Europe, so soon decay. Trees also growing in poor soils, which obtain their nourishment, and draw their sap and life rather from the air and water, than from the earth, are commonly shaky, being shook with the frost and wind. Those trees of the temperate zone, which grow where the frosts are not so intense, are generally of a more compact texture, and of greater durability: such is our British oak. And those which grow where there are no frosts, and under the hottest rays of the sun, are of the closest and hardest texture, and of longest durability in their own native climate.

All trees have a cause of destruction. The stupendous teak tree, if left to its fate, is devoured by white ants; the majestic oak, sooner or later, falls a sacrifice to the worm, or to the fungi. Time never fails to answer the purpose of nature. The decay of the timber of trees, in general, commences, and its progress continues, according as the fibres of the wood become divested of their natural tenacity, adhesiveness, and organization. This is occasioned by the alternate effects of wet and dry, when exposed in the open air (the wet swelling the soft fibres, which workmen call raising the grain, and the dry separating them), sometimes by the effects of heat and moisture combined, when in stagnant putrid air. The effect of intense frosts on vegetation, and on all substances, is, perhaps, the most insinuating, irresistible, and powerful of any, which operates on the texture of bodies. By frost, roots, fruits, and vegetables, are decomposed, and turned to corruption; young trees also are frosted; even stones and rocks become severed; scarcely any thing resists the force of frost, and its insinuating effect; glass becomes brittle; the strength of iron paralized. In short, frost has the power of steam or gunpowder; and heat and cold would appear as relative powers, varying in force, according to the intensity of either, from the medium degree, and both penetrating into substances in the same manner: for instance, a cannon, if filled with water, and the water securely confined therein, will burst, upon being exposed either to excessive heat, or intense frost. It cannot, therefore, appear extraordinary, that wood, when the pores are soaked and expanded by water, should be thus injured by the powerful and irresisible

force of intense frost. Even water, of itself, has great power to swell and expand the pores of wood; insomuch, that if a weight is placed on a piece of dry wood, and the wood afterwards wetted with water, the weight will be raised, by the power of the water insinuating itself into the interstices of the wood; and the fibres of a piece of timber, powerfully expanded by water, being afterwards operated upon by the additional force of frost, becomes still more overdistended. The timber, thus water-soaked, may be said to be almost in a mucilaginous state, and the frost to operate upon it, in a measure, as on potatoes, and other roots. By frequent exposures to wet and frost, the contexture of the wood becomes divested of its natural adhesiveness; and by remaining saturated, and in a frozen state, during a long winter, the pores become so fixed, in an expanded state, as never to contract themselves again.

There are various other causes of the texture of wood being destroyed, such as by bruises. A bruised place in timber will go to decay sooner than any other part; in like manner, as a bruised place in fruit will do. Saw-dust, therefore, is very liable to decay; and, if left in a ship, between the joints of timbers, in damp stagnant air, will cause dry-rot. Moreover, trees abounding in turpentine, being tapped and drained thereof, become excessively porous, and the fibres lose their natural connexion with each other; and the pores being filled with putrid matter, by being pent up in a ship, perish with dry-rot. Pitch-pine timber, from America, the substance of which is chiefly turpentine, when drained thereof, commonly decays in this way.

The Rhine oak, brought down that river from the forests, in large rafts, remaining for months soaked in water, and afterwards landed and exposed to intense frost, sustains very material injury; the fibres of the wood being expanded in so powerful a degree, lose their natural texture, and remain porous; and the water it imbibes, changing its state, and becoming corrosive, dry-rot ensues. The men of war, built in the late war by the French, at Antwerp, with the Rhine oak, were found by us in a state of decay from the dry-rot; some of them even while building.

The Canada oak and pine is also transported down the river St. Lawrence

in large rafts, continuing many months in water, and in that saturated state landed there, and exposed to long and intense frost, by which the same consequences happen as to the Rhine oak. Much of the Canada timber is in an early stage of dry-rot, when landed in this country: every attempt with a view to season this timber afterwards under cover, is but of little consequence; the pores never close again, and the timber being introduced in this porous state into our ships, the pores become filled with moisture from wet and damp, and being confined in stagnant air, turn corrupt and corrosible, and dry-rot takes place. Most of those of our ships which are now, and those which were infected with the dry-rot the late war, have either been partly built, or partly repaired, with materials from our North American colonies.

The oaks of North Europe are naturally very porous, and absorb much water; and these laying in the dock-yards abroad, exposed to heavy rains, and long intense frost, incur the like consequences as the Rhine and Canada timber. Both the Dutch and the Danish men of war are but of little durability. On the other hand, those ships built entirely and exclusively of wood grown up and hardened by the hottest rays of the sun, and never exposed to frost, are very rarely known to have the dry-rot, except the trees are cut down when too young.

Various have been the opinions as to the cause of the dry-rot: some have supposed it to arise from an insect; but this cannot be, for nothing of the kind can be discovered with the strongest magnifying powers: some have imagined the dry-rot to be a vegetable substance, arising from the vegetation of the juices in the timber; but this is also difficult to conceive, for the plank and thick-stuff used in men of war is boiled in salt-water for many hours, to make it supple, to bend to the timbers, and any vegetating principle must be destroyed thereby; and we find the plank and thick-stuff so boiled, is as commonly destroyed by the dry-rot, and as soon as any other part.

Some also have made a distinction between the wet and dry-rot; but, on investigation, there does not appear to be any such difference; generally

speaking, they are commonly both of the same nature, and are equally rapid in their destructive effects. A piece of wood destroyed by the wet-rot will, when dried, have the same appearance as if destroyed by dry-rot, excepting only that the former will have rather a darker colour than the latter. It frequently happens in a ship, that the lower end of a timber is destroyed by wet-rot, and the upper end by dry-rot; the only difference is, that one part has more moisture than the other, owing to the moisture setting more toward the lower end, and a regular gradation may be perceived in these cases, in the colour of, and humidity in, the timber. Considering the various appearance, and the different circumstances attending the destruction of timber from dry-rot, it would appear that a more appropriate name might be found for this decay of timber, than that of the dry-rot—the Danes call it the fire.

Although the decay of timber from dry-rot differs from the usual decay in its progress, the effect is the same: a decomposition, or dissolving of the fibres. Almost every description of timber is liable to dry-rot; either from its nature, its condition, or from infection. Timber unseasoned, diseased timber (such as oak when foxy, druxy, and with white rush), very young timber, and timber whose texture has become fixed in a porous state by long frosts, or become porous by improper management, are liable to it from their condition. Sound, full grown timber, properly seasoned, is liable to it from infection; and in this instance it may be truly termed a premature breaking up of the constitution of the timber. In some woods the dry-rot is the natural decay of the timber, such as the black birch of New Brunswick, and the pitch-pine of Carolina.

The same causes which accelerate the dry-rot in one species of timber, will accelerate other description of decay in other timber; thus damp stagnant air, which promotes common decay in sound seasoned timber, will also promote the dry-rot in unseasoned or unsound timber (which has the seeds of corruption in itself), as well as in timber naturally subject to it; and also in timber liable to it, from being in a porous state, and imbibing water. The same woods decay differently, according to the situation and circumstances. Sound seasoned oak, if *by itself*, will decay in the natural manner gradually;

but if placed in contact with another kind of wood, which decays quicker and differently, the former will also decay quicker, and by the same process as the latter. The natural decay varies in different timber; black birch and pitch-pine by the dry-rot; some of the elms and birch in a very similar way; the English oak, when properly seasoned, and the hard close grain woods of the torrid zone, by gradual decay. In all cases, the more porous the wood, the more rapid the decay (excepting only such of the porous woods as are of an odoriferous nature, which in consequence of that property resist putrefaction).

The species of the dry-rot varies in different woods according to the nature of its sap juices, and to that of the putrid corrosive matter left in its interstices, by imbibing water: it is often like a reddish powder: frequently a fungi appears of a yellow cast, firm and large; but it is most commonly in the form of a whitish film, spreading out like cobwebs, interspersed with white particles in the pores of the wood; sometimes it is putrid matter or substance, formed from the juices or moisture in the pores of the wood, turned to a corrosive property by foul stagnant air. The cause of the dry-rot in unseasoned timber arises from the putridity and corrosiveness of its sap juices. Again, in timber whose texture remains open and fixed in a porous state, having lost its tenacity, or power of contracting its fibres, from being over-distended by long frost, the cause of the dry-rot is, its imbibing water, and the water changing its natural quality from being pent up in the pores in foul stagnant air, and filling the interstices of the wood with putrid corrupt corroding matter, produces rapid destruction to the timber; and in this manner the dry-rot takes place in Canadian timber, and in that from North Europe. The cause of the dry-rot in our English oak, as it is usually seasoned, is from the mode of seasoning it. It is left in a porous state, when the juices are all dryed from it, and the pores afterwards imbibing wet in the ships, it corrodes and destroys it.

When the dry-rot is communicated to a sound piece of timber by infection, it assumes various appearances, and also varies in its different stages of destruction. Near the sound part of a piece of timber upon which it has operated by infection, a stain is to be observed, with here and there a

whitish speck. A little further from the sound part, the stain becomes darker, and somewhat resembling white threads, as fine as cobwebs, extend themselves along in the pores of the wood; afterwards these threads become larger, so as to fill up the pores; and lastly, the adhesive connexion of the fibres of the grain of the wood being destroyed, and separating and getting filled up with a thin white film, the destruction is completed. The dry-rot in this instance may be compared in its progress and effect to a mortification in the human system. In places occasionally open to air, its destruction is much slower than in confined places; but damp situations, where there is warm stagnant air, always contribute most to the destructive operation of the dry-rot.

CHAPTER II.

On the Management of Timber Trees, and on the proper Mode of bringing the Materials into use for Ship-building, and how to procure a Supply of those of the best Quality.

IT is not alone the destruction of our men of war which has befallen us, in consequence of being compelled to use these foreign materials, so subject to the dry-rot; but we have to deplore another calamity, the enormous consumption of our own valuable native oak, occasioned by its being used and mixed up with those foreign timbers, as well in the building as in the repair of our ships.

Considering the prodigious magnitude of our navy, its perishing state, and the great scarcity of English oak, there being at this time not one quarter part of the oak timber, in the royal forests, that there was two centuries ago, the whole of those forests not yielding annually more timber than is required for building one 74-gun ship; and other parts of the country being also very much thinned of oak timber: every means should be used, not only to prevent its rapid decay in ships, but to promote its increase, improve its condition, and to use that little which remains with the utmost economy. It is a national object, and every motive, whether of safety, policy, or economy of our financial resources, should prompt us to pay most anxious attention to the subject.

We seem insensible of the superior quality of our native oak, because, by the abuse of it, its durability has been reduced to the level of that of the most inferior materials. The quality of our *native* oak is undoubtedly as good now, if not better, than it was formerly, owing to the improved and open state of the face of the country. In buildings, many centuries old, oak timber is to be met with, perfectly sound, hard and as heavy as green

oak, with even the *sap* on some of that timber not decayed. And instances are not wanting of its great durability in our navy itself, as may be witnessed in the Royal William, which lasted a century; and the Royal Sovereign, built in 1636, was found perfectly sound fifty years afterwards, and the timber so firm and hard, as almost to resist the edge of tools.

Our ancestors, from ages of experience and close observation, appear much more than ourselves, to have attained to the knowledge of managing the oak tree, with a view to its durability; and of the proper time and mode of felling. They were also particular, as to the place of the growth of a tree, the situation, and soil, with a view to its quality. Nor were they less particular as to the age of a tree, in felling, when at maturity, and not before it had attained its full growth, nor after it had gone back; and we find other trees, of the most durable quality, if cut down when very young, will not last: for instance, the teak, which is the most durable wood, if cut down when young, will soon perish in ships, by the dry-rot.

If we may judge from the appearance, weight, and solidity of the oak timber remaining in old buildings, and the state of preservation in which even the sap is sometimes found, it should appear, that the fibres of the heart of the trees were closely connected and divested of juices, previous to the tree being cut down; and that the sap itself was rendered of a more tough and solid texture. Hence, it is probable, the trees were seasoned standing with the bark upon them; for bark not being of much value in those days, was the more readily sacrificed, for the benefit of the timber. The process observed was probably as follows: a broad rim of the bark was, in the winter, taken off round the trunk of the tree, near the root; the sap also cut out with it, quite through to the spine; the main channel of the sap juices immediately under the bark, as well as through the pores of the sap, would be thus intercepted in their rise at the ensuing spring. The tree being, by that process, placed in a dying state, no fresh juices rising in the sap, or under the bark, to produce leaves, &c. These juices would fill up all the pores of the timber, there congeal, and turn to sap, and then to heart, and in two seasons become altogether an imporous solid substance; for a coat of sap substance being formed from the sap juice, under the bark

of the oak, in one season, and a coat of heart being formed from that coat of sap, which is in contact with the heart, in one season, it takes consequently two seasons to form heart from sap juices. The bark of the oak being a powerful antisceptic, would operate as an antidote against any putridity in the heart and sap of the tree. The tree probably remained standing some three or four years, until the heart had in this manner condensated into the utmost solidity, the sap become contracted and tough, and the whole without juices or corruptive matter. This is probably the cause of the sap on oak timber in our old buildings remaining so sound; and also of the specific weight of the heart of such timber in old buildings, being equal in specific weight to the timber in its green state, because the substance is the same in the former as in the latter, with this difference, that the whole substance of the former was consolidated into sheer heart, but that of the latter consists of heart and juices in the natural state.

Whether the foregoing was or was not the mode made use of by the ancients, in seasoning the oak, it would certainly be found, on trial, to be a very excellent method. Every one must deplore the present management of our native oak. The trees are felled in the spring of the year, full of vegetable juices, at once stripped of their bark, then almost immediately hewed and sided, with the fibres of the heart still in a vegetative state; thus the timber lays exposed to, and is rended by the summer sun, is afterwards soaked by the autumn rains, and lastly burst by the winter's frost. It is not in the nature of timber to endure all this, without sustaining in the onset the most violent check to its durability.

The management of the oak, as before described to be the probable mode of the ancients, is, perhaps, as good a one as any that could be adopted, for bringing our oak into the best possible state for durability; but one great objection to that mode is, the loss of the virtue and value of the bark; for, being left on the tree, its antisceptic powers are expended in destroying the putrescence of the tree, in its dying state; nor indeed could the bark be afterwards very easily taken off; and it is now become of too important use and value to be sacrificed.

A method might, however, be adopted, by which the bark could be saved, and also the spine of the tree be brought into a proper state for durability.

The method proposed is as follows: at the *first* rising of the sap juices in the spring, the bark should be taken off the tree standing; and in the month of November following a broad score, or notch, should be cut round the trunk of the tree, a little above the ground, and the sap taken out to the heart, in order to drain any moisture absorbed by the sap afterwards from the rains. The tree should remain standing, at least two years and a half after being barked, and at the latter end of the last year be cut down. The timber should then be sawed off to the converted lengths, and lay, with the sap on it, till the winter is over; the sap should then be entirely taken off to the heart, and the timber delivered into the dock-yards, in a round state, with all heart.

By barking the tree standing, the juices, no longer able to rise under the bark, to form sap and vegetation, will rise and congeal into sap in the pores of the heart of the tree; and this sap, formed in the pores, being there in contact with the heart, will, in the following season, turn to heart; for, as was observed before, the sap juices of oak congeal, and form a substance of sap in one season of vegetation, and that sap substance, which is in contact with the spine, or heart, changes its nature to heart also, in the course of one season of vegetation.

Thus, when the tree is felled, the heart will be found compacted to an imporous texture, and as hard as box-wood; and as no interstices would remain to contain corrosive matter, to generate decay, its durability would be equal to any timber upon the face of the earth; for, excepting in the cases of the oily and odoriferous trees, the great durability of the trees of the torrid zone arise entirely from the closeness of their texture. It is necessary the sap should remain on, during the winter, after the tree is felled, in order to fortify it against the frost. The extra expense of stripping the bark from a tree standing, and after its being felled, will not amount to one penny per foot, on the quantum of timber in a tree, wich is no object compared with the important addition to the quality and durability of the timber.

Oak bark being of so much value and importance, any measures to *increase the quantity*, as well as to promote the saving of it in proper season, demands attention. It is found, that a considerable portion of the outside of the bark may be pared off from fruit trees, without injury to the trees, and even productive of great advantage to their bearing. It remains to be tried, whether the bark of the oak may not be pared to a little depth, taking off about one-half its thickness; and if the bark would not grow again, and if the operation could not be repeated, from time to time, without injury to the tree.

The sap of the oak forms a large proportion of its bulk; that remaining on the larger English oak timber, when served into His Majesty's yards, in the rough state, is about one-eighth part of the contents of the timber; that in the smaller timber, one-sixth part; that on sided timber, thickstaff and plank, about one-eleventh part. But the sap is not only useless in ship-building, it is also extremely pernicious, actually causing the destruction of the heart of the timber itself; for the fungi attacks the sap, and by that means obtains access to, and destroys the heart.

It is to be further observed, that if the sap is taken off in the woods, near a ninth part of the expense of land and water-carriage of timber would be saved; the charges of which are very high, frequently amounting to half the first cost of the timber. Upon the delivery of one hundred thousand loads of timber into His Majesty's yards, without sap, at least fifty thousand pounds would be saved. This considerable saving is worse than sacrificed, because it is bestowed upon that part of the material, *the sap*, which is pregnant with the most destructive consequences. The serving into His Majesty's yards so much useless destructive material, as sap is known to be, at such an expense, is highly injurious and disadvantageous; while, on the contrary, the delivery of timber in a *round* state, *without sap*, is the most advantageous state for conversion, in which it can possibly be rendered.

It should, however, be observed, that it would be highly injudicious to take off the sap from the timber in the woods, unless the heart is previously consolidated in manner before described, it being indispensably necessary for

the timber to be seasoned standing, and brought into a state to stand the weather, before the sap is taken off.

The importance of having timber for ship building, in its best possible condition for durability, cannot be too strongly urged. If hay be stacked in a green state, the juices turn putrid, and it rots. It is the same with timbers, put into a ship in a green state, laid close together, and pent up in stagnant air; the sap juices in the timbers corrupt and corrode, and dry-rot ensues. *But timber for ship-building should be not only without juices that have a tendency to destroy it,* BUT THE FIBRES OF THE WOOD SHOULD BE CONSOLIDATED SO CLOSE AS NOT TO IMBIBE OR ADMIT OF ANY DESTRUCTIVE MATTER TO CAUSE DRY-ROT. A ship built entirely and exclusively of such materials would, with care, last a hundred years, and no dry-rot ever take place.

How infinitely better would such materials be than timber cut down in a vegetative state, and in that state sent into His Majesty's yards, there piled up in stacks, with the sap upon it, rotting and destroying the heart. Timber also served in, after having been sided in the woods, while green and full of juices; in this state the surface of the spine, suddenly contracting, binds up the vegetable juices in the heart of the timber, when putrefaction ensues, and it becomes perished, or else the surface rends and admits the rain-water, which is alike destructive. Who could walk round our dock-yards and not lament to see the prodigious quantities of materials (naturally of the best quality) rendered unfit for durability, spoiled in the bringing into use.

Oak timber cut down in a vegetating state, and dried (commonly called seasoned), becomes porous as soon as the vegetable juices are dried from its fibres; being introduced into a ship in this porous state, and there confined in stagnant air, the pores become filled with moisture, from the damps of the hold, and this moisture generating into a corrosible matter, from the foul air and warm breaths of the crews, produces dry-rot. In like manner oak introduced into a ship in a green state, and there confined in stagnant air,

with its pores filled with sap juices, those juices in like manner turn putrid, from the foul air and the warm breaths of the crew, become corrosive, and cause the dry-rot. Wood in either of those conditions, used in houses, or remaining in dry airy places, would last many years; but when pent up in ships, and confined in damp stagnant air, it perishes.

On the other hand, timber, having the pores filled with spiny substance, and consolidated to a mass of heart, by the operation of nature, while standing in the woods to season, with its bark off, being introduced into ships, would not be easily affected by damps and foul air, because the pores being closed, no matter could form in them to cause dry-rot. Drying timber, when its pores are full of its vegetable juices, is not the proper mode of seasoning, to render it in a fit state for the construction or repair of our men of war. Timber used for ship building should remain standing in the woods, to season (as has been before observed), until the pores are filled up with spiny substance, and the whole wood consolidated to a mass of heart: our oak in this state would last as long as any timber whatever; as long, indeed, as it is in the nature of timber to endure.

It might, however, be attended at first with some difficulty, to get the timber-merchants to contract for the delivery of the oak timber into His Majesty's yards, seasoned in that manner; because their money would be locked up so long in the purchase, before they would receive their payments from government. The landed proprietors might also raise objections to the trees standing so long on their estates after being purchased. These difficulties might, however, be obviated by government, by regulating the payments to the contractors, and making other provisions in the contracts, so as to enable them to make the necessary pecuniary arrangements with the landed proprietors; and when it would be generally known that the timber contractors could not purchase, unless the requisite conditions were complied with, the landed proprietors would soon come into the measure, and be induced to regulate the conditions of their sales accordingly; for the timber contractors are always the principal buyers, and looked up to by the landed proprietors in all large sales.

A system of improving the condition of our native oak being once established by government, the benefit would extend to merchant shipping; and also to the various purposes of inland consumption (to which the small timber and tops in the lots purchased by the timber contractors, are usually appropriated as not being serviceable in the navy), and thus such an improved condition of our oak would recommend the more general adoption of the measure. This mode of increasing the durability of our native oak would, in time, lessen the consumption, and thus cause the quantity left in the country to last the longer.

Whatever difficulties however may be anticipated with the contractors, or landed proprietors, in obtaining the oak timber in this improved state, there would be little or none in respect to the timber from the king's forests; as a system might be certainly adopted there, so as to have the timber brought into the best possible condition for use, before it is sent to the different yards. In regard to the English oak thick-stuff, and plank, used in the navy, it is of much consequence that the whole of it should be sawed at his majesty's yards, and immediately put under sheds out of the weather, and there remain till used; and it should be sawed from rough logs, after having stood in the woods to season, being delivered without sap as beforesaid.

The thick-stuff and plank now ordinarily used, being commonly sawed out of unseasoned timber with the sap on, the sap soon decays, and preys upon the heart. Those materials often lay dispersed about the yards exposed to all weathers, the wind and the sun, the rains and the frost, by which it becomes rent and split; the whole it is apprehended receives more or less injury, and some of it entirely spoiled. If the thick-stuff and plank were to be sawed in His Majesty's yards, from timber seasoned as beforesaid, there would then be a certainty of having those materials in the best possible condition for use and durability. Saw-mills might be erected in the yards for this purpose, by which much expense of manual labour would be saved.

It must be of the first consequence to season our oak standing, as then we obtain its longest durability; for if by this process it can be made to last

four times as long, there will be incurred only one quarter part of the consumption, and consequently of the expense.

Another improvement presents itself in regard to the quality of our native oak. There are different species of oak now growing in the kingdom: theVirginian red, Spanish white, chesnut-leaved, willow-leaved, striped-leaved, Durmast, Austrian, &c. &c. It is much to be lamented, that any foreign acorns should ever have been sown in this country; but either from avaricious motives, or for ornament, or variety, we find them to occupy the places of our valuable native oak. Planting should be considered a public virtue, and individuals should, for the sake of our navy, deem it patriotic and meritorious, to prefer the cultivation of the genuine British oak, notwithstanding its growth is slower.

The introduction of these spurious oaks into our ships, has the most baneful effects on their duration. The sowing of foreign acorns should therefore be discontinued, and none sown in future but those from such of our native oaks as are flourishing in their prime; and the largest acorns should be selected to be sown, for it is found that trees from large acorns have most heart, and least sap. Oaks should be reared from acorns, and not transplanted, for they not only thrive best, and grow larger, when reared from acorns, but the wood is found to last the longest. It is commonly observed, that those oaks which rise fortuitously are of the best quality. Care should be taken in training them properly during the early stages of their growth; to prune some of their lower shoots, leaving a good leader, or top, sufficiently capable of attracting the sap, and in time to shorten the leader, and thin the head; *leaving two opposite boughs, the one not less than eight feet below the other*, to take the office of leaders; by which management good compass-timber will be produced for the navy. Acorns should be sown in a deep stiff soil; a sandy poor soil produces shaky defective oaks; because the trees depend more on the elements than on the earth, for their growth and support.

The situation the most advantageous for growing oaks is the vicinity of the dock-yards, and of the principal sea-ports, where their value becomes so

much the more considerable, by reason of the land-carriage and freight being less expensive.

Nor is it of minor importance, that means should be used, or some system adopted, to encourage the growth of the oak to its maturity. Oaks require from 90 to 160 years growth, to attain a sufficient size for the navy. The interest of the landed proprietors induces them to cut down the trees before they attain their full growth. In its younger stages the oak grows more rapid than at a more advanced age. Individuals too commonly cut down the young trees, to enrich themselves, rather than to have the heartfelt satisfaction of letting them grow to maturity, for the good of their posterity, and of their country.

This important object might be promoted in a great measure, by introducing a system of revenue and bounty; by Government raising a revenue on oak trees, cut down when small, and applying that revenue as a bounty on such large timber as would be suffered to grow to the proper size for the navy; the revenue and bounty to be proportioned in such a manner as to promote the growth of large timber for the navy, without materially affecting the interest of the landed proprietors.

Our elm is a very important timber tree, and may be greatly improved in its quality, by a different mode of management to that now practised; its durability and strength may be so much increased, as to render it fit for nearly all the floor timbers, cross chocks and midships, lower futtocks of our men of war, of the largest class; to which purposes a great quantity of large and principal oak timber is at present used. Elm would also be suitable for planking the bottoms of our ships of every class, below their light draft of water, for which purpose foreign oak plank is now used.

The elm tree is naturally very porous, full of juices, and of a quick growth. It is usually cut down in the spring of the year, in a vegetating state. The juices then evaporate, and the fibres being left in a porous state, are powerfully operated upon by alternate wet and dry, and it soon perishes. If this tree were seasoned standing with its bark off, until the juices in the pores

were hardened, and the whole consolidated to one substance of heart, it would be a different timber altogether to what it now is, both in point of usefulness and durability. The proper method to attain this improvement in the condition of the elm, is—to take off the bark in the spring of the year, and to let the tree remain standing until one year after all appearance of vegetation ceases. It will shoot out leaves the first and second year after being barked, and cease vegetating the third year, at which time the pores of the wood become filled and hardened, so that no more juices can rise in them. At the end of the third year (during the winter) it should be cut down, when the wood will be found of a compact, imporous, heavy, and hard texture; and in that state its durability will be increased in a surprising degree. The narrow-leaved or fine-leaved elm is by far the best of any, and should be planted in preferenee to any other species; and made to grow in hedges in strong stiff land.

Nor have our other timber trees been any better attended to; the natural quality of our pines (the spruce, the larch, and the Scotch fir, in particular) are quite equal to the pines from our American colonies; and with proper care in the raising, pruning, seasoning, and felling, would be found to answer in ship-building equally as well as the fir-timber and deals imported from North Europe. For near a century past we have been the dupes of our northern neighbours, who by care and proper management in rearing and felling their trees, have brought their fir-timber and deals into the best condition for use; and we have been using these materials, while our own spruce, larch, and Scotch fir, though naturally equal to them in quality, have been out of repute; insomuch, that an universal prejudice has been raised against them; and thus, have our neighbours been enriched at the expense of our negligence and mismanagement. Attention is required to these trees; for upon that alone depends their value and condition. Care should be taken to prune off the lower branches, while young, quite close, in order to obtain long lengths, and a good size, clear of knots, and they should be felled when at maturity, and not suffered to go back or decay; and previous to being cut down, the bark should be taken off during the winter season, round the lower part of the trunk of the trees for a few feet up, and they should

continue standing at least four years afterwards (until vegetation has ceased a whole year), and then hewn down during the winter season. By such care and management the timber would become quite a different thing; of a solid texture, very durable, clean grown, and fine grain, and of proper lengths and sizes for the various purposes required. By thus improving these materials, they would acquire repute, and soon obtain a preference over the foreign firs, and fetch a better price in the market; and this would operate as an inducement to planting.

If due encouragement were given to the growth of the larch, the Scotch fir, the silver and Weymouth pines, and the white and black American spruce, we should not long be obliged to have recourse to our foreign neighbours, or to our colonies, for fir-timber and deals.

The expense of planting is much less now than formerly, owing to the great improvement in agriculture; and there are prodigious tracks of waste lands in the country, where these trees might be raised. The larch, in particular, grows faster than any other durable wood, and will thrive better in a poor soil than in a rich one, if not too much exposed. When seasoned properly, it is neither apt to warp, shrink, or rent; and is very suitable for joiners' work on board of ships; and fit for ships' decks, masts, and spars. It is not, however, so eligible for the timbers of a ship, in general, as our oak; but it would, nevertheless, answer for timbers in those parts of a ship, where decay does not so soon take place. The larch, if seasoned standing, would do for most of the floor-timbers, cross-chocks, and midship lower futtocks, for line-of-battle ships; which would save the consumption of a great quantity of the largest and principal oak-timber used in the navy. The Scotch fir will flourish in situations still more exposed than the larch, and grow to a great size in a poor soil, if there be only a proper depth of it. The spruce requires rather a better soil, and to be more sheltered. The cedar of Lebanus is also found to thrive exceeding well in forest lands, and would be a very valuable and desirable wood for the ornamental work, in the cabins and state-rooms of our ships.

Until our home resources of timber can be made to furnish an adequate supply for our shipping, and domestic uses, true policy requires us to procure the deficiency from our own colonies, rather than from foreign countries.

Every means should therefore be used to promote an improvement in the condition of the timber in our colonies, and also to import for the navy, that only which is naturally of the best quality. The black birch of New Brunswick, and the red oak of Canada, will not last three years in a ship; and the whole of those oaks and pines, which grow in the swamps in that country, are of the worst quality. Those which grow on the uplands, open to the air and sun, are of the better quality.

The red pine, the spruce, and the Canada *white* oak, are by far the best of the timbers from our North American colonies. The red pine and the spruce should be managed in the manner pointed out, in regard to the pines of this country; they should have proper attention to their cultivation, and be seasoned standing, and then their quality would be entirely altered, and most astonishingly improved. They would become equal in all respects to the same description of materials imported from North Europe.

The Canada white oak should be seasoned standing, with its bark on, having only about two feet of it taken off (at the end of the winter) round the trunk, a little above the ground. Twelve months afterward the sap should be cut out at that place to the heart, to drain off wet, and it should continue standing three years from the first operation, to season and consolidate its fibres, and be felled at the approach of the winter. By such management the Canada oak would become quite a different material, both in texture and durability, to what we have hitherto unfortunately experienced it to be. In seasoning this oak, it is absolutely needful to leave the bark on, in order to protect the tree against those intense frosts which prevail during the long winters in that country; for the timber being in a green state, very porous and spongy, would otherwise receive most fatal effects from those long and intense frosts; and, moreover, the antisceptic qualities

of the bark would, while the tree is standing to season, counteract its natural tendency to putrescence.

Another material injury which the Canada timber receives, is from its being transported down the rivers, to the shipping places, in rafts; for, by laying so long in the water, the pores of the wood become saturated with that fluid; and being exposed, in that condition, to long intense frost, the fibres are at length so fixed in a distended, porous state, that they ever after continue in that spongeous condition, notwithstanding every pains taken afterwards in this country, as with a view to season the timber. When put into a ship, large collections of corroding matter, generated by moisture, and stagnant air, fill up the pores, and dry-rot ensues. Owing, however, to the rapids in the rivers in that country, it would be impossible to convey the greater part of what that country produces in any other way; but so much of it, however, as local circumstances would permit, should be conveyed down in craft; and no other timber should be purchased for the navy, but that which is transported in craft.

The oak with which the ships are built, at Petersburgh, is brought down the rivers in craft, from a very long distance in the interior, being sometimes two years on its passage; and this mode of transporting the timber should be resorted to in Canada, in every instance where the rapids will permit; and, when landed, it should be put under cover, and remain so till shipped, and not left on the wharfs, exposed to the rains, the wind, the sun, and the frost. If similar precautions were taken with the Canada timber, its quality would be astonishingly altered. If a ship were built in Canada, of the oak and pine of that country, managed and seasoned as before-said, the important benefit would be made manifest, in the most satisfactory manner. It ought, moreover, to be observed, that no Canada oak should be purchased for the navy, but the middling sizes; the large overgrown trees, which have passed their prime, being commonly defective at the heart. The quality of the large trees is seldom so good as that of the middling size; and the middling sizes of it are most suitable for the navy.

Government might have agents and purveyors in Canada, to see that none

were shipped for the service, but what had been properly seasoned standing, and brought into the best possible condition for use and durability. Such a system would be equally beneficial to the merchants also, who contract with government for supplying American timber. Of late they have been subject to immense losses, from the large quantities found necessary to be refused at his Majesty's yards; insomuch, that many of the contractors have been ruined, by having so much thrown upon their hands, after having incurred all the expenses in the country, and of freight and insurance home, to deliver it at his Majesty's yards.

If a system could be introduced, by which the quality of the timber in the American colonies would be improved, so as to rival the Baltic materials in our own markets, those colonies would be very essentially benefited. Government might assist so desirable an object, by easing the duties, or even by allowing a bounty upon timber in that improved state, by which large quantities might be imported, and the consumption of our native oak thereby lessened.

In the year 1754, there was imported from North and South Carolina, more than one quarter part as much timber as was then contained in the whole of our royal forests; and our present American colonies might be made capable of affording the same relief, if only proper care and attention were shown to the condition of the timber sent to this country.

But there are other resources, from whence may be now drawn very considerable supplies of the very best timber, for the use of the navy; and it becomes a consideration, whether government ought not to avail itself of those resources, in preference to those from the North American colonies; for, with all due regard to the prosperity of any colonies, it is too much to sacrifice the duration of our navy by any longer use of perishable productions; and to sacrifice the little of our native oak which remains, by mixing them with it in the ships; and especially so, when those colonists have it in their power, by proper management, to render their materials fit and durable.

It is, however, quite proper, that recourse should be had to these resources of durable materials, in preference to the supplies of deck-deals from the Baltic, and of oak-plank from Dantzic. The latter is but of short durability, and moreover destroys our oak.

The resources alluded to are Spanish Guiana, Trinidad, Havannah, the Oronooka, and the Amazon, where inexhaustible supplies present themselves of the most suitable and most durable woods. Arrangements might be made with the different powers in possession of those countries, for a supply of these desirable materials. Thick-stuff and plank should be sawed on the spot, to proper lengths, thicknesses, and breadths, for the navy, by which process much freight would be saved. Large quantities of teak-wood could be obtained in different parts of India: at Camara and Malabar, at Bombay and Surat, at Batavia; as also from the woods of teak, at Pegu, which are inexhaustible. Saw-mills could be erected at Rangoon, in Pegu; and also about Surat and Bombay, and other parts near the woods for the purpose of sawing the teak into thick-stuff and plank. It should also be edged to proper breadths, previous to its being shipped; a great quantity of which could be brought home in our East India ships, in lieu of dunnage, at very low freight.

These woods are not only of great durability, but would agree with our native oak, and add to its preservation. They are suitable for wales, clamps, ceiling, spirkitting, plank-sheers, top-sides, and the bottoms, of our men of war. At the Bermudas, the Floridas, and the island of Cuba, abundant supplies of cedar might be obtained for the decks; the odoriferous quality of which would preserve the oak-beams from decay. The cedar, therefore, is particularly eligible for water-ways, and for the decks (except in the most wearing parts); and saw-mills might be erected at the several places for cutting the plank. There are also cedars up some of the rivers of West Africa.

The expense of importing these materials from so great a distance, would doubtless cause them to come high; but, that expense would not become a

consideration ultimately. Those woods, when mixed with our native oak, would ensure its durability. A ship built and repaired, from time to time, with such materials, mixed with our native oak, would last, at least, *three* times as long, and, with some of those materials, *five* times longer than ships built and repaired, from time to time, with our native oak, mixed with the materials from our American colonies, in their present perishable state. The saving would, ultimately, be immense, both in money and materials.

Nor is the distance to go for some of these materials so very important a consideration; for we have lately been obliged to go as far as Carolina for materials of much inferior quality. The quantities of pitch-pine imported from thence, for the navy, has indeed been enormous, though a material so very objectionable; for this tree superabounds with turpentine, which, after it is cut down, the sun absorbs from the heart. The wood then becomes dried up, and excessively porous. In that state it is generally introduced into our ships, when the pores become presently filled with moisture from the damps of the hold; and there from being confined in stagnant air, grow putrid and corrupt, when the dry-rot ensues, and rapidly terminates its destruction. This experience unfortunately has invariably proved, and if we value our navy, and the preservation of the scanty remains of our native oak, the use of pitch-pine in our ships should never again be resorted to, if possible to be avoided. Indeed, much of this timber, from having been tapped and drained of its turpentine while standing, is in a perishing state previous to its arrival in this country.

Some difficulties will doubtless be experienced in obtaining the more durable woods for the navy; but every effort should certainly be made to get them; as from the use of timber of so destructive a quality as that from our American colonies, the navy has actually fallen into a state of decay, and the expense of keeping it in repair must be very serious under our financial difficulties. Our native oak is moreover rapidly exhausting, so that there is at this time not one-fourth the quantity of the description suitable for the navy, as there was at the commencement of the late war.

The importation of durable woods would obviate the necessity of *building any men of war out of the country;* a measure which, on every consideration, both of a political and domestic nature, should, if possible, be avoided. The forming of important establishments in India for building men of war, which establishments at some future day may be wrested from us by an enemy, and employed against ourselves, is a danger to be seriously contemplated: or should the territories become independent, the possession of such important establishments, stocked with skilful and able artificers, would operate as powerful engines to annoy our trade to China and the Spice Islands.

Again, it should be considered, that while we are building men of war in India, numbers of our own naval artificers at home are starving for want of work; and compelled to leave the kingdom, and seek employment in other maritime countries. It is certain that a considerable portion of them with large families, are in the greatest distress; and the principal merchant-yards in the kingdom dwindling away. Considering the perishing condition of our navy, and the inadequacy of His Majesty's yards to keep it up, there not being more than thirty dry-docks in all the royal yards for the repair of our immense navy; and further, that during the late war, one-half of the line of battle ships, and almost all the ships of war under that class, were of necessity built in the merchants' yards; and that from the timely exertions of those establishments our fleets have been rendered adequate, and thereby obtained victories of the first consequence; it surely becomes a most important object to preserve those merchant establishments against future pressing emergencies, and to discourage the building men of war abroad, and the emigration of our artificers.

There is an abundance of teak in different parts of India; but the great difficulty appears to arise from the expense of bringing it to England. On investigating this point, however, it will appear, that if proper measures were taken, the expense would be very inconsiderable. The cost of the teak in India is about half the price of our oak at home. Now the expense of freight home can be reduced one half, by converting or reducing the wood in the country to the lengths and dimensions actually wanted for use; so that

these materials so converted might be rendered into his majesty's yards at not a great deal more than the cost of English oak.

Supposing the price of teak in India to be 4*l.* per load in the rough state, add 10*s.* per load for the labour of converting the timber; and suppose two loads in the rough to produce one in the converted state, and that 14*l.* per load in its converted state be the freight to England, the expense delivered into His Majesty's yards, in a converted state, would be little more than 22*l.* 10*s.* per load. Comparing this with the cost and expense of English oak timber, when reduced to its converted state, the teak will be found to cost not a great deal more than the English oak. It may be made evident, that a ship can be built in England of teak and English oak timber together, at a very little more expense than one built in India: taking into the account of the latter, the expenses to Government in sending out stores, and in transporting the ship to this country. The most advantageous disposition of the teak timber, and of English oak timber, in the construction of a ship is, for the timbers to be of teak-wood, and the planks and thick-stuff to be of English oak. It is much more expensive to take out decayed timbers, and replace them with new ones, than to take off decayed plank and thick-stuff, and replace the same with new; consequently the most durable materials should be appropriated to the timbers.

It is found, that the hulls of men of war, built in India, have cost about the same per ton as those built in this country, in time of war; and further, that the teak is nearly half the expense of our oak timber. The timber required for the frame of a seventy-four gun ship costs, in England, about 15,000*l.*; and in India 7,200*l.* The whole timber required for the frame of a seventy-four gun ship, when converted, or reduced to its nett dimensions, in the frame, will contain about 800 loads, solid measurement; the freight of which from India, at 14*l.* per load, would be 11,200*l.*; this added to the first cost of the teak (7,200*l.*), would make the expense of the frame of a seventy-four gun ship of teak-wood, delivered in England, 18,400*l.* Now the frame of English oak costs 15,000*l.*; and the difference (3,400*l.*) is, what a seventy-four gun ship, built in England of teak-wood,

and of English oak together, would cost *more* than another ship built in England, of the usual materials.

The hull of the seventy-four costs the same in India as in England, in time of war; but then taking into the calculation the expenses to government, in sending out stores, officers, &c. and transporting the seventy-four from India to this country, and comparing all those expenses with the 3,400*l.* it would appear that the ship built in England of teak-wood and English oak, will come to little or nothing more than one built in India; and it can be made equally clear, in pursuing the calculation, that a seventy-four gun ship built here entirely of teak, previously converted in India, would cost government only about 6000*l.* more than the expense of building it in India, and transporting it to England. This saving, compared with the baneful consequences of resorting to the expedient of building men of war abroad, cannot be an object either in a political point of view, or under the other circumstances. Thick-stuff and plank could be sawed in India, and edged to its proper breadths, and cut off to the proper lengths: and the timbers also for the frames of our men of war of different classes, could be sawed out nearly to their dimensions, and thus the freight would be reduced one-half.

Every means should therefore be used to get these durable materials imported into this country, at the least possible expense, in order *to build our men of war at home*, with our British oak and these materials mixed together; in preference to using the perishable materials from North Europe, or those from our American colonies; and that system might be combined until the Colonists set about to improve the condition of their timber, or until our home resourses are improved, increased, and rendered adequate to the demands of our navy.

If a man of war can be built in this country of teak timber and British oak mixed, at little more expense than one built of Canada timber mixed with British oak, and the former lasts five times as long, the latter may consequently be considered to cost five times as much as the former. What,

therefore, can be the object of a small primary saving, compared with the importance of an ultimate saving, in ever seventy-four gun ship, of four times the cost of its hull; *viz.* 200,000*l.* to say nothing of the interest and compound interest of that sum, which would astonish the calculator, and particularly if he extended his calculation to the number of ships comprising the navy. It must appear, therefore, to be of the utmost importance to have timber of the most durable quality, and in the best possible condition for the construction of our men of war; and this little additional expense to obtain that durability, must be allowed to be the best economy.

CHAPTER III.

Precautions in Building the Ships submitted, and in the Care of them while in Use.

WITH a further view to the durability of our men of war, much care is required to be taken of the materials when in the different dock-yards, also in the use of them, and in the mode of building our ships; the best of materials may be greatly injured for want of care and attention in these respects.

Timber, thick stuff, plank, and deals, should, as much as the nature of the service will admit, be kept under cover till used, and not left about the yards, exposed to all weathers, rent by the sun and wind, soaked with rains, and injured by frosts.

Those ships are most subject to the dry-rot, which have been partly built or repaired with materials (such as Canada timber) which have been long exposed to the effect of intense frost, when saturated with water, and thereby rendered excessively porous; while, on the other hand, those ships, built in parts abroad where no frosts are ever known, and of materials the growth of those parts, are seldom found to have the dry-rot, unless communicated by the infection of materials introduced into them afterwards; which materials had been injured by frost, or were naturally tending to the dry-rot.

All our men of war should also be built under cover, which is of the greatest importance to the workmanship, and to the durability of our ships. This practice has obtained in foreign parts for centuries; at Venice, they are not only built, but, after being built, they remain under cover, and are not launched till wanted; and these ships, after remaining under cover forty or fifty years, have been found perfectly sound and fit for service.

The method which has been adopted in this country, of seasoning the ships in frame, exposed to the effects of all weathers, is, perhaps, the most injudicious of all methods, and should be entirely discontinued. It would be a better plan, to put all the timbers, beams, &c. &c. after being sawed to their proper dimensions, under a shed in a dry situation: leaving a space between them, and an opening at the north and east sides for the admission of a gentle current of air, and there remain under cover till seasoned or wanted.

Great caution is also to be observed in disposing of the various descriptions of timber, in the construction of the ships, not to place those in contact with each other which are known to disagree in their nature, and to destroy each other. The oak of North Europe, and of North America, prove extremely pernicious to our native oak, and destroy it in one-third of the time it would last by itself.

The practice, also, of introducing timbers in the building and repairing of our ships, which have been taken out of old ships, has a very destructive tendency; a decayed piece of timber, placed in contact with a sound piece, will hasten the destruction of the latter; and if such old timbers are taken out of ships infected with dry-rot, there is a hazard of its being communicated to those ships into which they are introduced: for however sound those old timbers may appear, yet the seeds of the dry-rot may be within them, and the least infection is sufficient to spread destruction wherever they are placed. Precaution should also be taken, that no sap whatever be left on the edges or sides of the timbers, thick-stuff, or plank, in any part of the ship; every attom of sap should be taken off clean to the spine; it being of no use, and highly pernicious and destructive—producing the fungi, which soon destroys the sap, and afterwards extends the destruction to the spine or heart of the wood.

In constructing our ships, every economy should be observed in the quantum of the materials used, by duly regulating the dimensions of the different parts according to the substance necessary for the strength required; more than that is not only a waste of the materials, but adds to the weakness, and not to the strength of the ships. The different component parts should also

be so arranged, as to support each other with the strongest and most pliable effect. One of the French men of war, taken by Lord Nelson at Aboukir, was constructed with diagonal trusses in lieu of cieling, by which mode much plank and thick-stuff was saved. The only disadvantage to this mode of increasing strength is, that of its lessening the pliability of a ship.

The dimensions of the timbers in our ships are generally larger than is necessary, and the timbers are placed too close together. The French, Spanish, and Portuguese ships, have smaller timbers, and larger openings between them, than our ships, by which much timber is saved, and more room given for circulation of air; which latter is of the utmost importance to the duration of a ship. There should be, if possible, an open space between the timbers in every part. Experience has almost invariably proved, that those parts of a ship's frame where the timbers are placed quite close together, go first to decay; therefore, as few fillings as possible should be put between the timbers in any part, for they obstruct the admission and circulation of air, and cause decay.

It is also essential that openings be left between the floors and futtocks, for the water to move freely between them; by which a constant motion of air throughout the ship's frame would take place by the rolling of the ship at sea, and stagnant vapours dispersed. By letting daily a quantity of water into the hold, at sea (which should afterwards be pumped out) not only the duration of the ship would be promoted, but also the health of the crews. The usual fillings between the floors and futtocks should only be introduced at the lower part between these timbers; the openings at the upper part, under the inside plank, should be left open to give room for the water to move about; and as these fillings are intended to obstruct in some measure the entrance of the water into the ship, in case of any of the outside planks being knocked off by the ship's striking the ground, care should be taken, not only that the fillings be well secured at the under part and caulked, but also that each plank, as it is brought on under the flat of the floor, should be as well caulked as possible between the timbers and fillings, and the inner-side of the outside plank, in order to obstruct the passage of the water in any direction between the timbers and the outside plank: caulking between the timbers and plank is not usual, though without that

process the purposes for which these fillings are intended are not so fully answered.

The durability of ships depends so much upon a circulation of air in the inside, that every opportunity in the construction should be embraced to leave openings and apertures for the purpose. The seams in the sides, in-board out of the weather, should none of them be caulked and puttied. An opening to the timbers should be left under the clamps of the forecastle and quarter-deck, and all along under the gangways, to give vent for free circulation of air through the ship's frame; the edges of the planks in these openings should be trimmed in a direction downward, to prevent any water and filth from getting down between the timbers. The timbers of the frame ought not to be die-square; there should be no more bearing for the plank than absolutely necessary to take the fastenings of the outside and inside plank; the edges of the timbers should be chamfered away, or rounded off; this would admit more air to the plank and timber, and the frame might also be sawed out of smaller timber in consequence of not being die-square—and thus economy be promoted, as well as durability; indeed, it is commonly observed, that waney timbers (provided they are free from sap) last the longest. The upper edges of the beams of all the decks should also be chamfered away or rounded off, and only so much flat surface be left for the deck to rest on, as is requisite for fastening the planks and deals; this would procure the admission of more air to the beams and decks, and add to their preservation; and this would also allow of the beams being sawed out of smaller timber.

Care should be taken, in the workmanship, that no saw-dust be left in the joints or faying parts of timbers; workmen are apt to introduce the saw between joints, to fit the work close, and to leave the saw-dust in the cavities. This dust imbibing water, and being confined in foul stagnant air, causes dry-rot. The joints of all the timbers, beams, &c. &c. should be carefully cleared of saw-dust, chips, and other filth, and either charred (for charcoal is antiputrescent), or else smeared with fish-oil, sulphur, and rosin. This is also efficacious in preventing fungi, and in checking the progress of dry-rot, and destructive to vermin: the composition should be prepared as

follows: the oil should be boiled, and when taken off the fire, a small portion of rosin be immediately thrown in, which being stirred about, will soon melt and incorporate with the boiling oil: as much finely pounded sulphur should then be introduced, and well stirred together, so as to make it of the consistency of thin paint; it should be then smeared between the joints with a brush. This composition will preserve timber in a surprising manner. There is also an oil in Pegu, in the East Indies, a great preservative of wood, which might be imported for this purpose.

Care should also be taken in the workmanship not to bruise the wood in any part, particularly round the heads of bolts and nails. Bruised places in timber go the soonest to decay. The custom of workmen dipping the ends of copper and iron bolts intotar, to make them drive more free, is very prejudicial: the tar corrodes the iron, and injures the copper. Bolts should be dipped in oil, which would not only make the bolts drive easier, but tend to preserve them.

The custom in the dock-yards, of boiling the plank and thick-stuff in water, in order to render them supple, to bend round to the fore and after-parts of the ships, is exceedingly injurious to these materials. The pores of the wood become thereby expanded, and the strength and elasticity of its fibres being weakened, it becomes brittle, and in a more porous state than before being boiled. In that state, being confined in the ships, the pores become filled with the putrid moisture arising from the damps and foul air, and cause corruption and rapid decay. Other means might be adopted to make them supple, less injurious to the materials; by heating the plank and thick-stuff in sand; or by heating them over fire till they are supple; either of which is a preferable method to the ordinary one; as by both the moisture from the wood becomes absorbed, its pores contracted, and its durability promoted. Whenever circumstances render it indispensable for plank or thick-stuff to be boiled, the water in which they are boiled should be strongly impregnated with a quantity of cedar or teak shavings or chips thrown into it, the odoriferous quality of which, insinuating itself into the pores of the wood, renders it less liable to the dry-rot. The kiln should be frequently cleaned, and the water changed; and salt-water should never be used

for this purpose, the salt left in the pores being so injurious to the fastenings.

Nothing, in the construction of a ship, requires more attention, than the fastenings; upon the sufficiency of which the strength of a ship as much depends, as it does upon the sufficiency in the dimensions of the timbers, planks, and other of its component parts. The fastenings should always be of a strength, proportional to the parts united and secured by them: so that the one should hold till the other breaks. Fastenings should, moreover, be of the strongest and toughest materials, in order to be of as small a size as possible; for, when the fastenings are large, they require large holes, and these weaken the parts secured.

Tree-nails are a very inferior fastening: the material is too weak; they generally soon decay; and it is round about the tree-nail holes that the timbers go first to decay. Moreover, the tree-nail holes wound and weaken timbers very much; and, from their large size, render a larger scantling needful, than would be required, if bolts were introduced. Tree-nail holes should never be bored in the timbers, in the ranges of the fastenings of the different decks. The latter fastenings are quite sufficient for the outside and inside plank, with a few additional bolts. It sometimes happens, that the most important timbers in those parts (and upon which the strength of the upper-works depends), is so perforated and weakened with tree-nail and bolt-holes, as to be scarcely strong enough to bear their own weight. Tree-nail holes should be kept dry, both before and after the tree-nails are driven. Whatever tree-nails are used, should be made of wood of the toughest, closest grain, and be always seasoned under cover. Pitch-pine tree-nails (which have been used in some of our men of war), are extremely weak. Under the torrid zone there is a choice of tough, close-grain woods. Persons might be sent abroad to make tree-nails from them: a ship-load of which would last the navy a considerable time. The Spanish and Portuguese rarely use tree-nails, and their ships are durable.

Bolts are certainly a more secure fastening; and they should be driven through both the inside and outside planks; and the points well secured,

either by a clinch, by a ring and forelock, or nut and screw.—The screw-bolt is frequently used by the Dutch and the French. La Legurienne, a French brig of war, of sixteen guns, taken by the Petterell, in March, 1800, was fastened thoughout with screw-bolts. A vessel was put up in France, by order of Bonaparte, which was fastened with screw-bolts, taken to pieces again, and stowed in one of the ships that accompanied him in his expedition to Egypt, with a view of being put together again in that country. The Spaniards use the spike-pointed bolt, and turn the end into the wood. The different modes of fastening, have each of them their advantages, according to local situations and circumstances. Where the strain tends, in a particular manner, to draw out the bolt, the forelock upon a plate is the strongest fastening of all. The clinch does very well for the lower fastenings of a ship, where the wood is not apt to shrink; and the screw-bolt is to be preferred above water, where the parts secured require to be kept close together, but are liable to shrink. A ring, or plate, should always be introduced at the point of the bolt, for the nut to press against. These several fastenings should be used where best adapted.

The tree-nail is, in every respect, the most inferior fastening, with regard either to security, durability, or economy. In our woods, copper fastenings are the most durable, of the most permanent strength, and the least destructive to the timbers. In the end they are the cheapest fastening also that can be used in our ships. Their durability is such, that the same bolts will do for two or three ships successively, and lastly, for frame-bolts; and after their service is over, they will be worth nearly half as much as they cost at first. The only objection to copper-bolts is, that they are sometimes liable to loosen and start, from the straining of the ship; they should, therefore, be particularly well secured at the points.

The use of iron bolts and nails should be discontinued as much as possible, for the sea-water and the acid of our oak corrode and destroy the iron, and this in its turn decays the wood. There are but few woods with which iron agrees: in timber of an oily nature, such as teak, or live oak, iron will last for many years, without much rust from sea-water. In such woods, iron is unquestionably the best fastening. The teak will preserve iron some time

from the corrosion even of copper; but in our woods, iron is highly pernicious in itself, and is of little durability. The Romans used brass, or copper, hardened, in building their galleys; but never iron, (the ancients had some method of rendering their copper hard, as our iron is hardened into steel); nor do the Chinese use iron in their vessels. The fastenings of the bottom and upper works of our ships, the beams and knees, the nails of the decks, the in-board work, and fastenings of all the masts, should be of copper, and not of iron; in short, as few as possible of iron bolts or nails should be used in our ships; and particular care is required that iron and copper fastenings should never come in contact in wood, for if the wet penetrates those parts, the wood will be destroyed, by the corrosive operation of the two metals on each other. The frame-bolts should all be of copper.

The use of tar in the hulls and masts of our ships, is very destructive both to copper, and to iron fastenings; no pitch or tar should come in contact with either. In the Brazils the Portuguese use a composition made of lime and fish-oil, instead of a mixture of pitch and tar. A composition much of the same nature, called *chunam*, is made use of in the East Indies, which would answer much better than pitch and tar, as it is a preservative of iron and copper. We have an bundance of lime, as well as fish-oil, and it would be more political to encourage our fisheries, by using fish-oil, than to import so much tar and pitch from foreign countries. Instead of pitch, the Chinese use *kiang*, which is a composition of lime and a rosin, exuding from the *tonyea* tree; and at Surat, a gum, called *dammar*, is used instead of pitch; in Bengal they use a mixture of lime, fish-oil, and sugar; of these latter materials we can have an abundance, and the composition will be found equally as pliable, adhesive, and tough, and to stand heat and cold better than pitch, without being much more expensive.

The use of paint, putty, and white-wash, in the interior of a ship, is not absolutely necessary, and is injurious to the wood. It prevents the moisture in the inside of the wood from evaporating through the pores, and drying off at the surface; which moisture, from being pent up by putty, paint, and lime-wash, turns putrid in the heart of the wood, and causes it to perish by dry-rot. Out of the weather, the surface of the wood had better

be left in its natural state, and it would require only to be kept clean, to look always neat. The oak, in old buildings, which has lasted so many centuries, is not painted.

But the durability of our ships, and also the health of the crews, very much depend upon the care and attention of the officers, when at sea. Officers should consider, that they have in their charge, the health, as well as the lives of the seamen. They should see that the ships are kept clean, and thoroughly ventilated; a considerable quantity of water should be let into the ship's hold every day, and pumped out again; for the water from the leaks of the ships being strongly impregnated with the copper, and afterwards laying among the iron ballast, becomes extremely pernicious to the wood; and by pumping the ships out often, the stagnant vapours below are dispersed.

The same means that tends to the durability of ships, promote the health of the crews, and conduce also to the preservation of the provisions and stores on board. Ships should frequently be fumigated. There is not, for that purpose, a more excellent thing than tobacco; it insinuates itself into every part of a ship, even into the pores of the wood; it corrects foul air, and arrests putrefaction. All damaged tobacco, instead of being destroyed by the officers of the excise, should be dried, and distributed to the men-of-war, and, from time to time, burnt in their pump-wells. In hot climates, and in cases of malignant distempers on board, it would have the most important effects. Formerly the galleys in the men-of-war were down below, and then the fires, drawing the noxious vapours, had a like salubrious effect.

Great attention is further required, to keep the ships tight, and well caulked in their upper-works, particularly when on foreign service in hot climates; in the Mediterranean especially. The seams should be frequently examined, and caulked in any parts found open, otherwise the rain-water penetrates the seams, gets in behind the planks, and rots both planks and timbers. Many of our finest ships, it is to be believed, owe their destruction to the neglect of caulking when abroad, which is but too frequently neglected, merely to save the appearance of the paint-work. Ships on foreign stations,

particularly those on the Mediterranean, should be supplied with a much larger stock of paint, than that usually allowed; it being wanted to put the paint-work to rights, as often as caulking is required. There would then be much less probability of neglect, in caulking the upper-works, which omission is certain destruction to a ship, even though she were built of the very best materials, and with the utmost care. The officers who have this important duty in their charge, should be made responsible for any neglect of it; and if, when the ships come home to be repaired in His Majesty's yards, it is found on survey, by the officers of the yards, that the dry-rot has taken place, from a neglect of keeping the ships properly caulked when abroad, they should be directed to report upon it.

There is nothing in a ship of more anxious consequence than anchors. Many thousands of brave men have lost their lives, and numbers of ships wrecked, from their insufficiency. All anchors for the navy should be made of the very best iron that can be procured; manufactured with the utmost care, and upon such a principle as, on trial, proves to be the best; and their sufficiency in point of strength should be proved, before being delivered to the ships.

Proper care should be taken of our ships, while laying up in ordinary; they should be sheltered as much as possible from the sun and rains, and kept clean; and every means used to admit a free circulation of pure air into the internal parts. No part of the in-board-work out of the weather should be painted, in the new ships, when laid up. Ships which have been in service, should be kept immersed to the same depth in the water, as when in service; otherwise that part which may have been, for some years before, under water, being exposed to the weather, will go to decay; for the wet being absorbed by the sun and wind, from the parts so long before under water, the wood becomes excessively porous, and the rain-water penetrating the pores, the effect of wet and dry soon causes destruction; our ships, in consequence, often decay sooner laying up in ordinary, than in active service. As much stone-ballast should be put into the ships, when laid up in ordinary, as will bring them down to that depth in the water as they swim to when in service; and it should be ballast, free from metallic substances,

and also quite clean, free from earth, sand, or rubbish, such as flint, coarse gravel, lime-stone, &c.; and the ballast should be placed in the ships so as to preserve their sheer; none should be put before the fore-mast, nor abaft the mizen-mast; the greatest part should lay in the midships, gradually lessening the quantity towards the fore and mizen-masts.

Upon the whole, it appears that a variety of circumstances claim most serious attention, with a view to upholding our navy. But it is no easy matter to bring about a material alteration, in a system so extensive and complicated. At all events, it behoves every one, who has the welfare of his country at heart, to suggest, at this juncture, every means for improving the condition of our navy. It must, however, be observed, that several suggestions in the foregoing, of minor consideration, are not new; but, being proper, and not yet acted upon, are therefore brought into view.

The measures now adopting by government, of building the ships under cover, &c. (which have been also adverted to), are, so far as they go, very proper; and will add much to the durability of the ships; but then they are measures of a secondary consideration only; and do not strike at the root of the evil. Unless the materials are brought into a state for durability, as has been fully exemplified, all secondary measures will prove of but little comparative avail.

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